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DS-50002745A. MEC2206Eng04/18

ISSN 0262 3617
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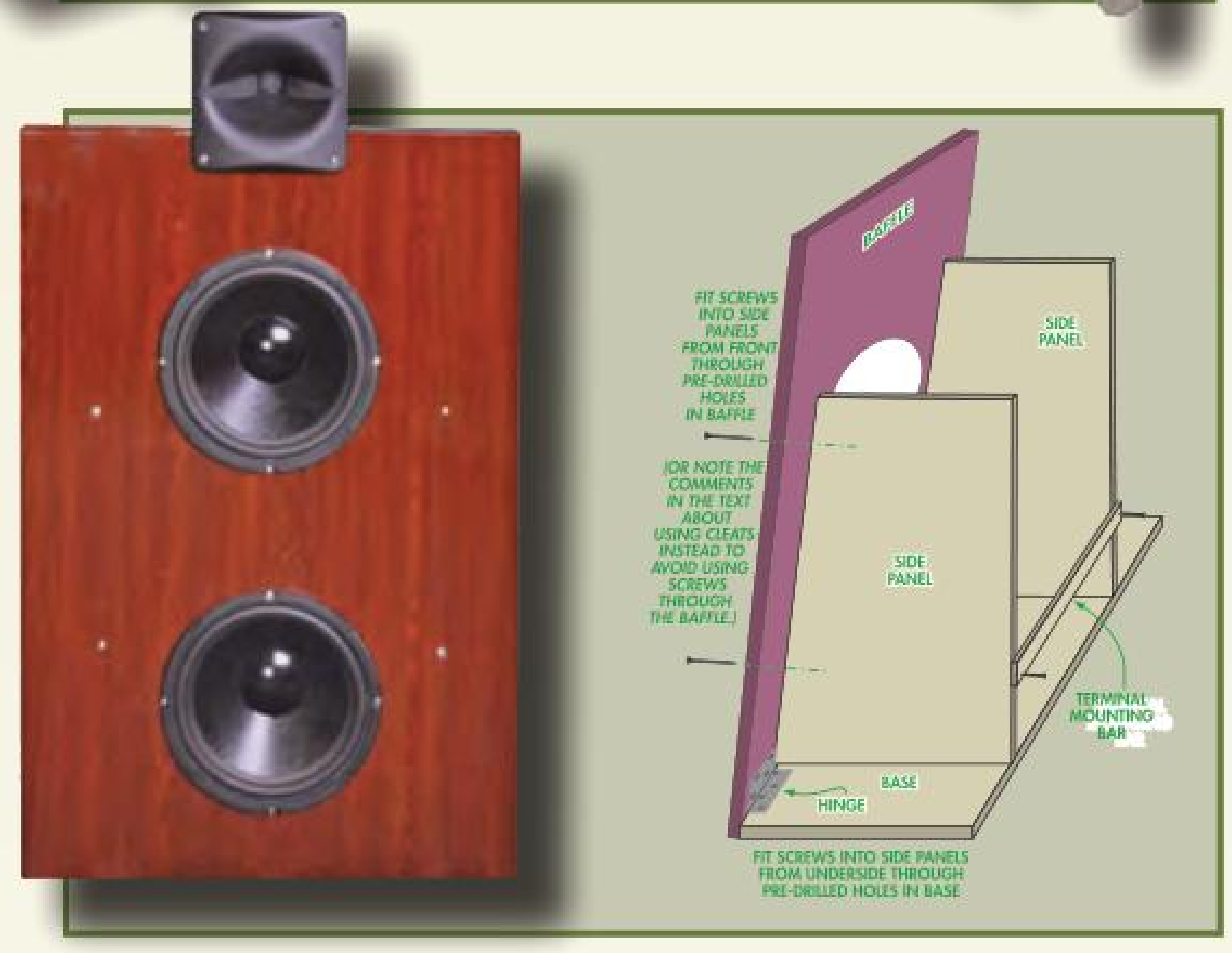
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VOL. 47 No. 11 NOVEMBER 2018

Editorial Offices:
EVERYDAY PRACTICAL ELECTRONICS
EDITORIAL Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299. **Fax:** 01202 843233.
Email: fay.kearn@wimborne.co.uk
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EVERYDAY PRACTICAL ELECTRONICS

Barry Fox

Those of you who read the magazine properly – cover to cover, of course – will have immediately spotted a gap at the beginning of this issue. In October, Barry Fox penned his last regular *News* column. I asked *EPE's* publisher Mike Kenward how long Barry had worked for us and he simply couldn't remember a time when we hadn't had a regular Fox contribution. Mike suggested I ask the man himself… who duly responded with, 'I have been contributing for at least a hundred years, long before the merger of *Practical Electronics* and *Everyday Electronics* into *EPE* – although some of the early material had to be written under my pen name Adrian Hope. Back then I was working as a patent agent, and the stuffy patents profession didn't think much of journalists and journalism.'

Those of you who like to follow Barry's musings will be pleased to hear that he will continue to write about Hi-Fi in his role as European Editor for the US-based subscription newsletter *Consumer Electronics Daily*. Barry also plans to spend more time on his photo archive website – **www.tekkiepix.com** – mainly trying to secure funds to widen its scope from video to audio and beyond.'

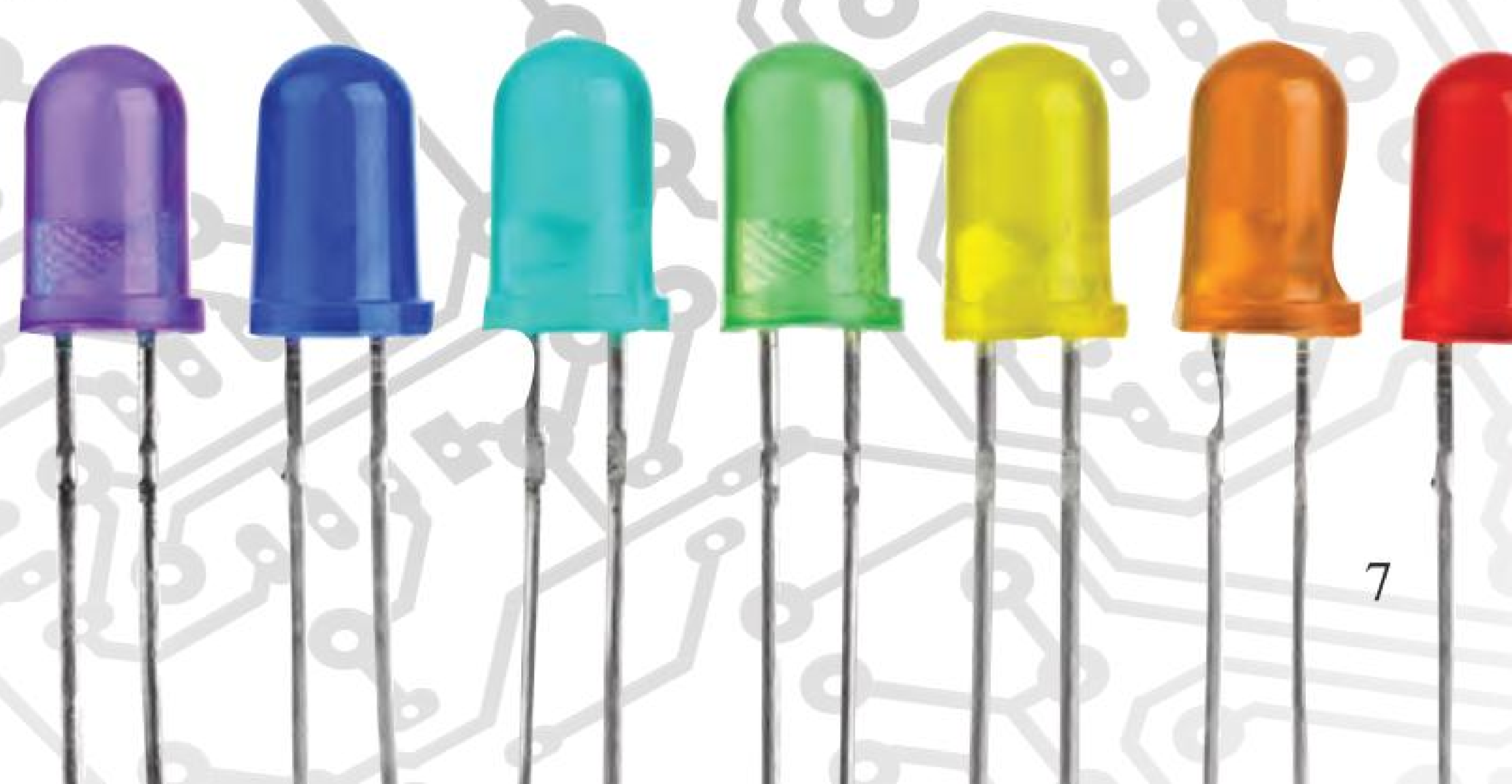
Fortunately, Barry has not completely retired from *EPE* – he has promised occasional reviews and commentary on equipment and systems, which I will definitely look forward to reading.

As *EPE's* editor, Barry's departure left me with a little bit of a quandary. In the Internet era does it really make sense for a monthly print publication to print 'news' – answer: probably not. And in any case, how do you follow an act like Barry – answer: you can't. So, for the time being I have decided to retire the *News* pages. I think those two pages are better spent on the kind of material that you can't just pull out of the online ether. Whether it's Jake Rothman's *Audio Out* column or Alan Winstanley's *Net Work* pages, *EPE* should concentrate on publishing material that can't be found anywhere else. Agree? Disagree? Do let me know!

Before I sign off on this topic I must say a huge 'thank you' to Barry from all of us here at Wimborne Publishing. Barry's journalism and professionalism made editing his work a pleasure and it has been a privilege to publish his reviews, opinions and reports from far-flung corners of the globe.

Hunting for parts – Part 2

Last month, I discussed at some length sourcing parts for the projects we run from our partner magazine *Silicon Chip*. I explained that we hope to expand the range of *Silicon Chip* parts from our somewhat limited current offering of just PCBs. This is still very much our intention, and initial discussions with *Silicon Chip* are promising. However, I must confess that an extremely busy month has got the better of me and you will have to wait just a little bit longer for firm details. I apologise for the disappointment, but do want to reassure readers that it is just a temporary hold-up; more details soon – really!



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Your money down their drain

It's like your worst nightmare. You see a disaster unfolding before your own eyes, powerless to prevent an entirely predictable outcome, caused by total incompetence.

I'M TALKING ABOUT SOMETHING that is hitting the pocket of all of us who pay gas and electricity bills. But before we suffer the bad news, let's begin on an optimistic note. Much as you might admire the advantages of electric-powered cars (and other road vehicles), the time taken to recharge their batteries is a major inconvenience.

Now, however, scientists at the University of Glasgow have announced a new type of energy storage system that could revolutionise EV (electric vehicle) uptake and drop their charging time from hours to seconds. In what is called a 'flow battery system', a nano-molecule that can store electric power or hydrogen gas is employed in a new type of hybrid energy storage system that can be used both as a flow battery and for hydrogen storage (see: **www.bit.ly/2wbPXyE**). When a concentrated liquid containing the nano-molecules is made, the amount of energy it can store increases by almost ten times. Since the energy can be released as either electricity or hydrogen gas, the system could be used flexibly in situations that might need either a chemical fuel or electric power.

Pumpable liquid

One potential benefit of this system is that EVs could be charged in seconds because the material is a pumpable liquid. This could mean that the battery of an EV could be 'recharged' in roughly the same length of time as a petrol car's tank can be filled. The old battery liquid would be removed at the same time and recharged, ready to be used again. Professor Leroy Cronin, the University of Glasgow's Regius Chair of Chemistry, states: 'For future renewables to be effective, high-capacity, flexible energy storage systems are needed to smooth out the peaks and troughs in supply. Our approach will provide a new route to do this electrochemically and could even have applications in electric cars where batteries can still take hours to recharge and have limited capacity. Moreover, the very high energy density of our material could increase the range of electric cars, and also increase the resilience of energy storage systems to keep the lights on at times of peak demand.'

Thanks to nanotechnology developed at the University of Glasgow, 'fill 'er up' may soon work with EVs.

Ever been sold a pup?

A few years ago, a friend of mine in his late seventies successfully convinced his wife that despite its elevated price, they needed a new music system. The icing on the cake for him was that it included a DAB radio tuner, which would future-proof their £500 investment should the government cease transmissions on FM. Imagine how they both felt a few years later when DAB+ was introduced and their fabulous sound system could not be upgraded.

You'd be feeling equally hoodwinked if you knew that the smart energy meters being installed are about as useful as a Betamax recorder without tapes. As one of my friends quipped, 'smart people have dumb meters; dumb people have smart meters'. He continues: 'The supposed benefits are all illusory: you can get them from an energy monitor costing less than a tenth of the £400 price of a smart meter. Just clip the sensor around the fat wire at the meter, then plug in the remote display in the kitchen or wherever. Worse, to beat the 2020 deadline, they're still installing the obsolete SMETS-1 smart meters which go dumb when you follow the government's advice to save money by switching energy supplier!'

More dumb stupidity

A commentator in another publication belies the assertion that smart electricity meters can mitigate the risk that peak demand might exceed supply. If smart meters could interact with smart appliances this might be valid, but the meters being installed now do not have this capability, nor is there any agreement yet on how this should be achieved. The logical step would be to pause the current installation programme until the standard for fully interactive meters has been agreed in the UK, and ideally across all of Europe.

This was emphasised in a report issued in July by the British Infrastructure Group of Parliamentarians: *Not so smart: a comprehensive investigation into the roll-out of energy smart meters* (**http://bit.ly/2o8AafD**). The report does not mince its words, stating: 'The roll-out is consequently at serious risk of becoming yet another large-scale public infrastructure project delivered well over time and budget, and which fails to provide energy customers with a meaningful return on their investment. The planned £11 billion roll-out has been plagued by repeated delays and cost increases … and … although the entire programme has been funded by customers through higher energy bills, not by energy suppliers themselves, they are not guaranteed to see the majority of the savings that do materialise. Suppliers are still rolling out obsolete first-generation smart meters, well past their November 2016 deadline … and … will continue to offer these meters until October 2018, and install them into January 2019.' What an indictment of these well-paid money-wasters.

Hidden agenda?

Will these meters save energy anyway? Informed sources indicate that there's not much fat left to trim; most people already have energy-saving light bulbs and efficient fridges, and unless you leave the windows open with the central heating and lights burning 24-hours a day, there's not very much more you can do unless you shiver in the dark. The strong likelihood is that with 30-minute metering, peak-time tariffs will become far more expensive. Not now, of course, because OFGEM will introduce variable 'time of day tariffs' only when everyone has been duped into having a smart meter. Thankfully, consumers are under no formal or legal obligation to accept a smart meter, so hold onto what you've got – and save your money!

NET WORK

by Alan Winstanley

A cloud of smoke

One benefit of working in the always-on cloud is that software and IT maintenance is delegated to anonymous data centres that might be located halfway round the world, and you simply pay to rent their services. Some cloud-based email and office packages such as Google Gmail are free, while Google Cloud's startup G Suite package with 30GB cloud storage is just £3.30 a month and Microsoft's Office 365 Personal with 1TB of cloud storage starts at £5.99 a month. Adobe sells its own cloud-based design and graphics products with subscription lock-ins, clearly a profitable strategy that has seen Adobe's digital media sector turn over $1.5bn in the second quarter, a revenue growth of 22% year on year, reports Adobe.

As well as cloud-based email and office applications, there has never been a wider choice for hosting websites themselves. GoDaddy Website Builder and **Wix.com** are just two low-cost template-driven sites aimed at non-designers. For maintaining smaller websites and blogs, web page contents can be updated by logging into a content management system (CMS) built, for example, using Wordpress or Joomla, allowing straightforward edits to be made over the web. These systems require constant vigilance and regular patching though, something that a managed and paid-for service will take care of for you – otherwise, users have the headache of managing systems for themselves. Larger websites have totally bespoke CMS systems that can cost anything from thousands to millions of pounds to design.

I have never been a fan of online editing and CMS systems. They can be slow and clunky to use and frustrating to navigate around. Images and files still have to be slavishly uploaded from hard disk, and it's easy to go live only to find errors afterwards that need more editing. Web pages can also be designed and edited offline using PC-based software like Adobe Dreamweaver. Historically, our website at **www.epemag.com** has been managed this way by the author, using a dedicated Windows PC running Dreamweaver software. This PC contains a full mirror copy of the entire EPEmag website and all its supporting files. Only after website updates are finalised and checked offline are files uploaded by FTP onto the live web server. If nothing else, this traditional and robust regime is inherently faster to use than any cloud-based system and has been proven to work extremely well for many years. It keeps the operation manageable for everybody concerned, including the accountants!

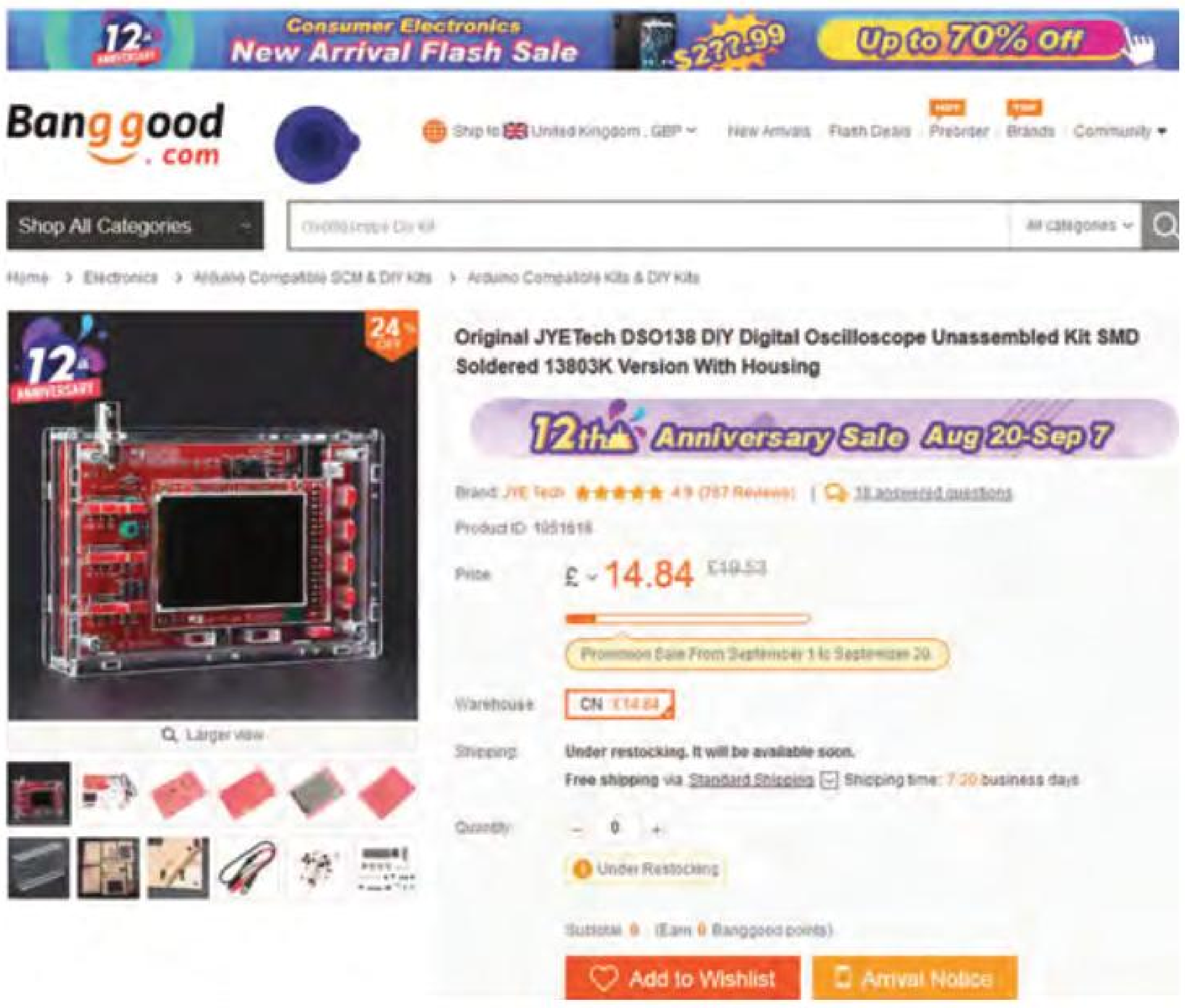
The flip side is that, compared with cloud computing, the onus is of course on the user to maintain the PC's software, OS and hardware, backups, LAN, anti-virus and all – and as I found out last month, the ability to solder also helps. During a recent *EPE* update, the specially-built homebrew PC kept slowing down before crashing altogether, which caused much head-scratching. Eventually, the PC was taken apart to reveal the northbridge heatsink dangling off the motherboard. One of the clips holding the 'sink in place had detached itself from the board. It looked like a disaster in the making that could cost days and many hundreds of pounds to fix, but the PC was stripped down and the one-cent clip was soldered back into place. Fingers crossed, an hour later we were back in business. That's just as well, otherwise *EPE's* website would have been in a laggardly state of disarray for some time!

Enter the dragon

Earlier this year a product review of a cheap and cheerful bare-board digital oscilloscope (the DSO138) sourced from the Chinese vendor Banggood drew the ire of one correspondent who thought *EPE* was reviewing a cheap fake copy, thereby encouraging the sale of pirated goods. Since the 'scope was clearly being sold online under the manufacturer's JYE Tech Official Store pages on Banggood, *EPE* had no reason to question its authenticity, otherwise it would have been down to JYE Tech, not *EPE*, to force Banggood to remove it from sale.

The web has made the world a smaller place and buying from China from eBay or AliExpress is second nature for many readers. AliExpress is the retail arm of Alibaba, the giant Chinese wholesaler and retailer platform whose turnover puts it in the top five of the world's most valuable companies. In Britain, Alibaba has forged strong links with UK postal group Royal Mail, which enables Chinese exporters to deliver to the UK within two weeks. Royal Mail claims China is their largest import country partner, so it makes sense for them to cosy up to merchants yearning to export to Britain from the Middle Kingdom. Other vendors of Chinese gadgetry and assorted wares include **www.goodluckbuy.com**, **www.e-chinaexpress.com** and **www.joybuy.com** (not tested by the author) which has a very slick website.

A year or two ago I met the CEO of a Chinese clothing factory. When the subject of own-label exclusivity and copying designs arose, the diminutive lady laughed and exclaimed 'I copy them! They copy him! He copies me!", stabbing the air several times. Copying something while making it sufficiently different to circumvent copyright law is very commonplace, but sometimes



Original JYETech DSO138 DIY Digital Oscilloscope Unassembled Kit SMD Soldered 13803K Version With Housing

Price £ 14.84 £19.53

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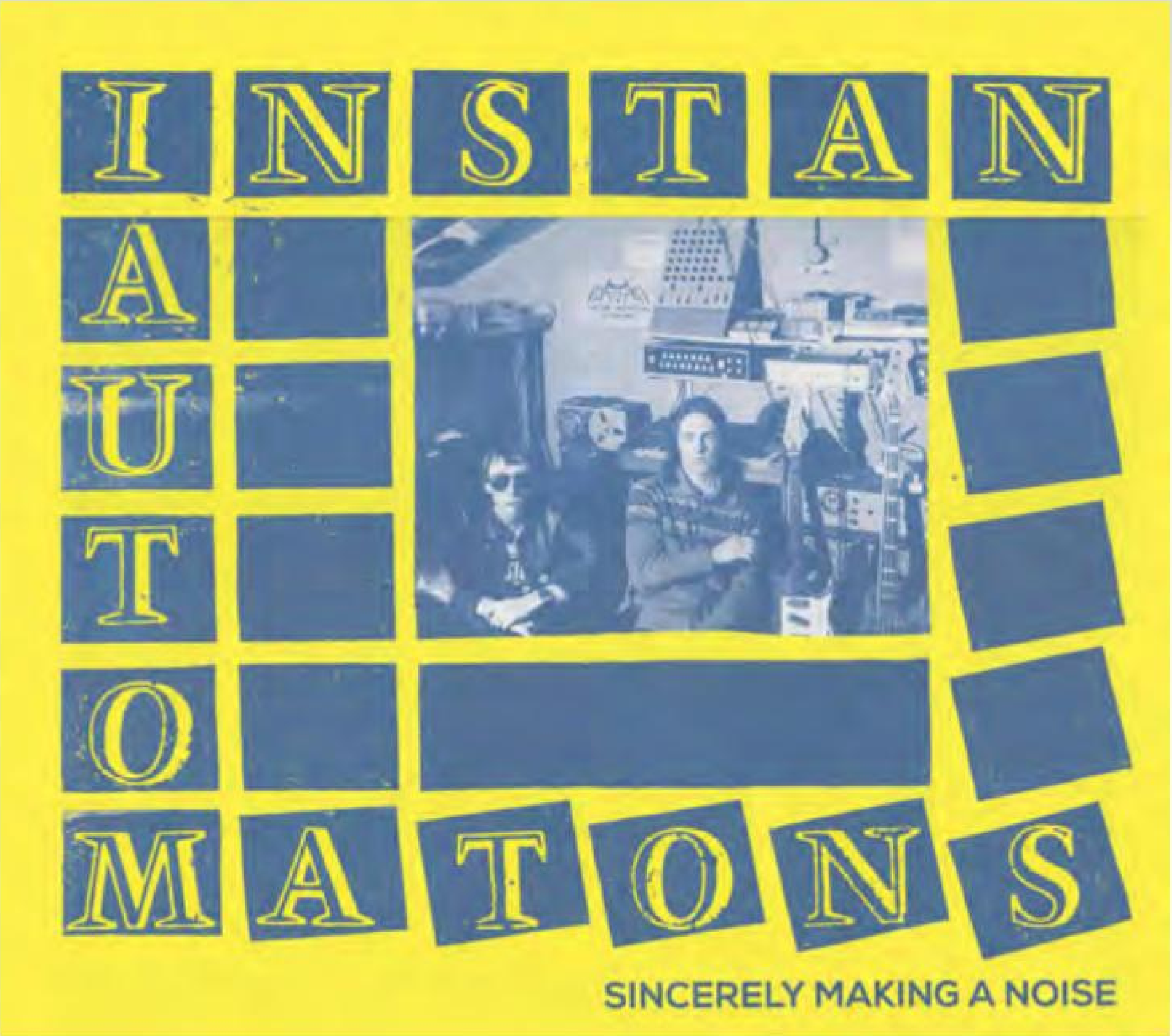
Shipping Under restocking. It will be available soon.

Under Restocking

China-based vendor Banggood is one of several portal sites selling gadgets and merchandise direct to the UK.



The Instant Automatons (1979-82) are credited with offering the first free music 'downloads' onto their fans' own cassette tapes. Left, Mark Lancaster, right 'Protag' (Martin Neish) in their sound studio.

copycat behaviour pushes the boundaries of intellectual property law to extremes. For example, compare the genuine Range Rover Evoque SUV and the Chinese-built Landwind X7 seen in the AOL news report at: **https://tinyurl.com/yat6o8q4**

It's a commercial fact of life that piracy and intellectual property infringement are rampant, and portal websites are stuffed with cheap but authentic-looking copies of genuine goods. Buying online sometimes feels like a bit of a gamble, but AliExpress, Amazon, eBay, PayPal and Banggood offer their own guarantees should things go wrong. The term 'drop shipment' refers to larger distributors despatching goods on behalf of retailers and handling all the logistics, and it's very common to see the same 'white label' goods re-branded for another vendor – or are they pirated copies instead?

Supplier credibility and reassurance are major factors influencing a decision to buy (the other is that of buyer benefit: what's in it for me?), and buyers will hesitate if they don't really know who they are dealing with.

Nevertheless, most of us welcome the odd grey polybag of cheap bits and pieces from Chinese sellers, but a recent packet supposedly from a Chinese eBay source somehow came from Kyrgyzstan instead. Good feedback ratings help build credibility, but deeply suspicious and phony five star reviews of Chinese goods also appear on major websites. Although the web brings us more choice than ever, Chinese brands know they must work extremely hard to establish their reputation if they are to capitalise on winning repeat business from us.

The dawn of music downloads

Downloading music from the likes of Amazon, Spotify and iTunes has become a no-brainer for many Internet users, even though they miss out on the tactile experience of slipping a vinyl LP or CD from its sleeve and reading its cover notes. In the, UK vinyl sales account for about 3% of music consumption and vinyl sales are the highest in two decades, claims The Vinyl Factory (**https://thevinylfactory.com/plant/**) which in the early 2000s acquired the legendary EMI vinyl pressing plant in Hayes, Middlesex. Today, they press more than one million records a year. In the US, vinyl sales are up 19% according to *Digital Music News*.

So it was with delight that I was recently presented with my first new LP in probably 25 years or more, a very limited edition work – *Sincerely Making A Noise* – by Mark Lancaster, who in the 1980s formed a band called The Instant Automatons. Mark wrote the lyrics and played guitar, synth and sax, while fellow Automaton Martin Neish handled bass, synths, and vocals in this embryonic 1970s band that had a fascination with making sounds electronically.

Lacking a record deal, Mark and Martin had a fantastic idea that shunned music industry norms: fans could mail in a blank tape cassette and SAE, and a free copy of The Instant Automatons' music would be dubbed and mailed back to them on their own cassette. They duly advertised in the music press and it became the forerunner of the UK DIY cassette culture. Soon, dozens and then hundreds of small bands were releasing their music on DIY cassette the same way. *The Guardian* cited this as the first example, in the UK anyway, of a band offering a free 'download' of their music (**http://bit.ly/2NOeJf6** – contains language), long before the Internet made music no farther than an effortless mouse click away.

For the writer, The Instant Automatons holds a special place in history, not just because they offered Britain's first free music downloads but because all three of us went to the same school together. It was the late Martin Neish who in 1974 showed me a copy of *Everyday Electronics*, a DIY hobby electronics magazine that totally fascinated him. As school kids, we often shared electronic adventures before going our separate ways – and here I am today. Martin became known as a good sound engineer as well as musician, under the name of 'Protag' – see the tribute at: **https://tinyurl.com/ycw2m8la**

You can listen to some early music on YouTube at: **https://youtu.be/cHu3OhJqR-k** and the Waterden label webite is still operated by Mark Lancaster at: **www.waterden.net**. His bio appears on Kindle at: **https://tinyurl.com/y9xrdsm8**

See you next month for more *Net Work*. You can contact the author at: **alan@epemag.net**

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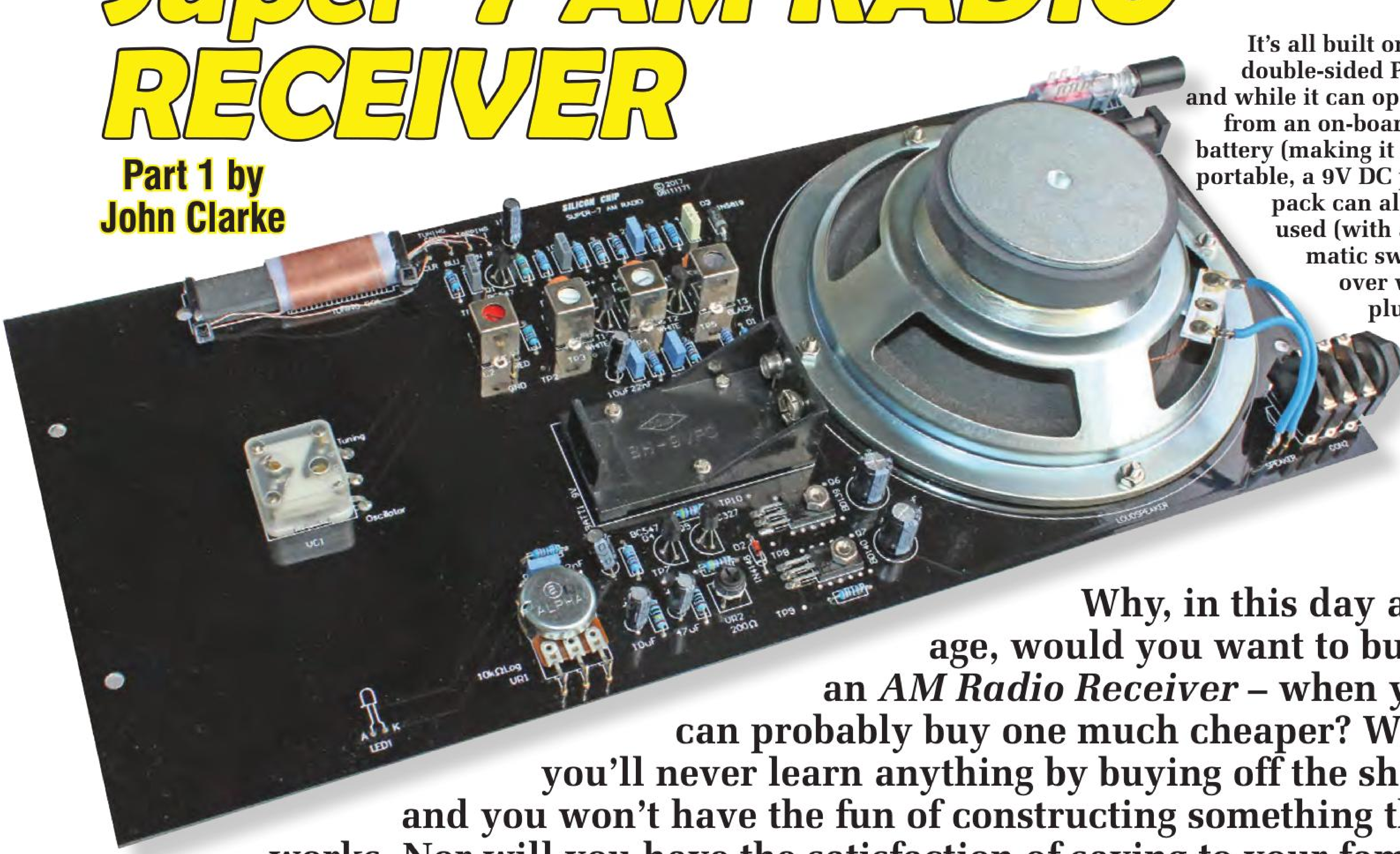
Super-7 AM RADIO RECEIVER

Part 1 by John Clarke



It's all built on one double-sided PCB – and while it can operate from an on-board 9V battery (making it truly portable, a 9V DC plugpack can also be used (with automatic switchover when plugged in).

Why, in this day and age, would you want to build an *AM Radio Receiver* – when you can probably buy one much cheaper? Well, you'll never learn anything by buying off the shelf, and you won't have the fun of constructing something that works. Nor will you have the satisfaction of saying to your family and friends: 'Look at this! I built it myself!'

The ***Super-7 Superhet AM Radio*** makes a great beginner's project – whether you're 8 or 88!

It is nice and easy to build since all the components mount on a single PCB. They're all standard components (no surface-mount devices to worry about) that are easy to get and they're laid out in a neat manner, making assembly simple and also allowing you to see how it works.

It's powered from a 9V battery or 9V DC plugpack and it automatically switches from battery to the mains supply when it's plugged in.

Audio output is loud and clear from a built-in 100mm (4-inch) diameter loudspeaker, but it also has a headphone jack, which automatically disconnects the speaker when in use.

This set has good sensitivity and selectivity as well as reasonably low distortion.

It fits into a custom-designed acrylic case, with a transparent back, so the components are protected but you can still see its workings. It has a large (hand-span) tuning dial showing the current frequency.

Once built and aligned, you will end up with a fully functioning radio reminiscent of radio sets from the past but using modern technology.

It's called the '*Super-7*' partly because it is a superheterodyne, but also because it uses seven silicon transistors (plus two diodes). One transistor is used for the mixer/oscillator, two for IF amplification and four for the Class-AB push-pull output stage. We'll explain all these terms as we go.

This month we will describe the *Super-7 AM Radio* circuit, with the assembly and alignment details to follow.

If you know nothing about AM radio technology or the operation of a superheterodyne receiver, please see the accompanying panels titled 'What is AM radio' and 'The Superhet AM Radio Receiver' before moving on to the circuit description.

Circuit description

Refer to Fig.1, which shows the complete circuit of our *Super-7 AM Radio.* Each section of the circuit is labelled so that you can see how it relates to the block diagram in the panel on page 16, which explains how a superhet works.

The circuit does not have an RF amplifier stage, so the antenna signal is coupled directly to the mixer stage.

The antenna coil (T1) is wound on a small ferrite rod. The high permeability of the ferrite material allows a compact antenna of this type to pick up signals that would otherwise require a fairly long standard antenna.

The primary coil is tuned in a parallel resonant circuit by one section of the plastic dielectric tuning gang, VC1. Trimmer capacitor VC2 is in parallel with VC1 and is set during alignment of the AM radio so that stations appear at the correct location on the dial.

A secondary coil on the ferrite rod couples the tuned signal into the base of transistor Q1, via a 22nF capacitor, and Q1 functions as a self-oscillating mixer.

It oscillates at a frequency set by the parallel resonant circuitry connected to its emitter, ie, the primary of T2 plus VC3 and VC4.

This oscillator is tuned by the second section of the tuning gang, VC3. Again, VC4 is a trimmer, connected in parallel with VC3, and is set during the alignment process so that the oscillator frequency tracks the tuned frequency with the correct offset of 455kHz.

The oscillator transformer (T2) has its secondary winding connected in series with the collector of Q1. This provides feedback to Q1 to sustain oscillation.

The output signal of the mixer/oscillator appears at the bottom end of this secondary and is fed to the primary of transformer T3.

This is adjusted (via its integral tuning slug) to be resonant at the intermediate frequency of 455kHz.

So it selects the intermediate (difference) frequency and filters out most of the original frequency as well as the oscillator signal and sum products. Its primary also forms the collector load for transistor Q1 and a 1.2MΩ parallel resistor sets its Q, determining its bandwidth.

The output IF signal from the secondary is applied to the base of the first IF amplifier transistor, Q2. A 27kΩ resistor from the positive rail provides its base with a DC bias current. Its 1kΩ emitter resistor is bypassed with a 22nF capacitor to maximise the gain.

Transformer coupling

These transformer coupled stages may seem odd to readers who are used to seeing circuits in which transistor stages are directly coupled, ie, without capacitors or transformers.

There are several reasons for using transformers. The first is that, as stated above, the IF transformers filter out unwanted frequencies so that the transistors don't waste power amplifying unwanted signals, which could potentially cause them to saturate. They also improve selectivity, by limiting the bandwidth of the signal being amplified.

Second, the IF transformers provide the right degree of impedance matching between the relatively high impedance of the collector circuits of the transistors and the relatively low impedance base circuit of the following transistor. This optimises the available gain.

Note that in each case, the collector current of the transistor passes through only a portion of the transformer primary, and this is part of the intended matching process.

Note also the circuitous path followed by the DC collector current for the mixer transistor Q1. The current passes through part of the primary of the 1st IF transformer (T3) and then via the secondary of oscillator transformer (T2), before arriving at the collector of Q1.

Now turn your attention to the second IF transformer, T4. Its primary is the collector load for Q2, while the output from its secondary is fed to the base of Q3.

Besides a few details of the biasing of Q3, this amplification stage is essentially identical to Q2 and it provides more gain for the signal before it's fed to the detector.

Detector diode

This role is performed by diode D1, but while the detector looks simple, there is more to it than first appears. The detector diode is driven by the secondary winding of the third IF transformer, T5.

This diode performs two tasks. First, it detects or demodulates the amplitude modulated IF signal to produce an audio signal, and second, it produces the AGC voltage which is used to control the gain of the 1st IF amplifier, Q2.

D1 is a Schottky diode, selected for its low forward-voltage drop of about 0.3V. Germanium diodes, with a 0.2V forward-voltage drop, have traditionally been used as detectors but they are getting hard to find.

D1 rectifies the negative-going portion of the IF signal, resulting in a negative output voltage. Its anode is connected to a 22nF capacitor and provides the first stage of RF filtering, and then via a 2.2kΩ resistor to a second 22nF capacitor for more filtering of the final audio signal before being applied to the 10kΩ volume control potentiometer, VR1.

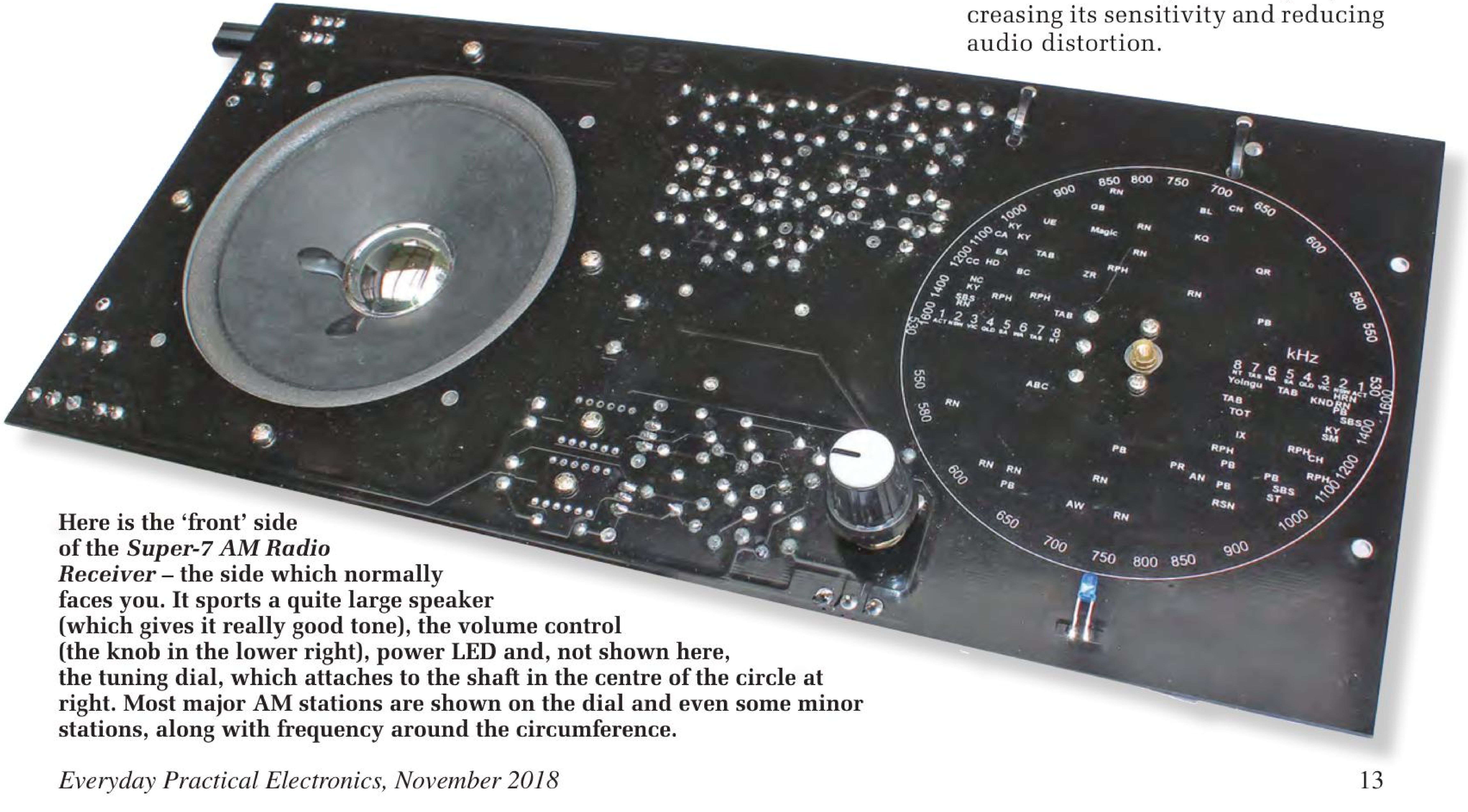
The demodulated signal is also coupled via a 3.3kΩ resistor to a 10µF filter capacitor, which forms a low-pass filter with a –3dB point of 5Hz. Thus, the audio portion of the signal is eliminated before being fed back to the base of Q2 via T3's secondary.

The AGC works as follows: if a large signal is being picked up, diode D1 will produce a larger than normal negative DC voltage and this will tend to throttle back the base bias voltage of Q2.

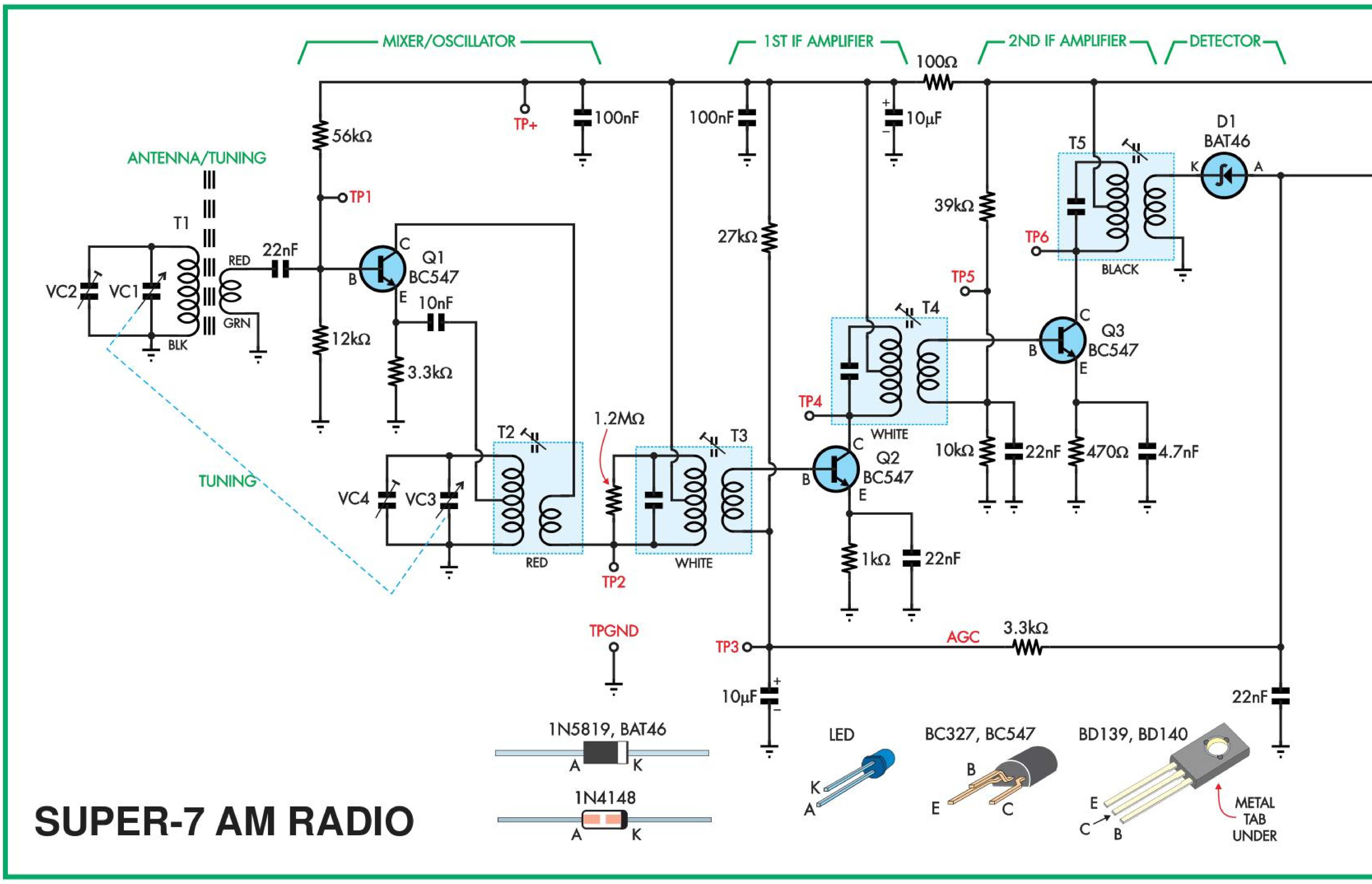
So Q2 will conduct less current and its gain will consequently be reduced. The stronger the signal, the greater the gain reduction and hence the chance of signal overload is greatly reduced.

Note the rather complicated bias network for the base of Q2. Current passes first via the 27kΩ resistor, the 3.3kΩ and 2.2kΩ resistors associated with diode D1, and then via the 10kΩ volume control pot, VR1. The base current flows from the junction of the 27kΩ and 3.3kΩ resistors via the secondary of the 1st IF transformer (T3).

Another thing to consider is that the current flowing through the 27kΩ and 3.3kΩ resistors will tend to forward-bias D1 slightly, offsetting its forward voltage and slightly increasing its sensitivity and reducing audio distortion.



Here is the 'front' side of the *Super-7 AM Radio Receiver* – the side which normally faces you. It sports a quite large speaker (which gives it really good tone), the volume control (the knob in the lower right), power LED and, not shown here, the tuning dial, which attaches to the shaft in the centre of the circle at right. Most major AM stations are shown on the dial and even some minor stations, along with frequency around the circumference.



SUPER-7 AM RADIO

Having the bias current flow through the volume control pot is not ideal; pots with DC flowing through them will cause a little noise during rotation.

Potentiometers become even noisier if DC current flows via the wiper, but this does not happen in this circuit since we use a 10µF coupling capacitor.

Audio amplifier

The audio signal from the volume control is fed to a four-transistor amplifier consisting of Q4, Q5, Q6

What is AM radio?

When radio stations first began broadcasting in Australia (and for many decades after), they all used the amplitude modulation (AM) system, predominantly using the 'broadcast band', which covers 531kHz to 1.602MHz.

The other transmitting system – FM, or frequency modulation – only commenced in Australia in the 1970s and uses a higher frequency band, from roughly 88 to 108MHz. And more recently, the digital system, DAB+, transmitting on a range of frequencies around 200MHz, has started mainly in major cities.

Apart from the difference in frequencies, trying to listen to AM with an FM receiver (or vice versa) will not be successful. The same applies to DAB+ on any other receiver.

AM transmission

AM is relatively simple: it involves transmitting a signal with a fixed frequency (known as the radio frequency [RF] carrier) but its amplitude (power) is modulated, or varied, by the voltage level of an audio signal such as from a microphone or music being played.

The receiver is tuned to the carrier frequency and once it picks it up, it's 'demodulated' to produce a voltage that's proportional to the signal amplitude. The resulting signal is then amplified and fed to the radio's loudspeaker.

The state-of-the-art analogue approach for receiving an AM signal is the superheterodyne (or 'superhet') principle, invented by Edwin Armstrong in 1918. The first commercial AM superheterodyne radios were put on the market by Radio Corporation of America (RCA) in 1924. Later, RCA licensed other manufacturers so that the design was used worldwide.

Prior to the superheterodyne, radios were either crystal sets or used the tuned radio frequency (TRF) principle, of which there are a number of variations. In a TRF receiver, all amplification up to the detector (demodulator) takes place at the frequency of the incoming signal.

The superheterodyne radio brought with it two major advantages over previous circuits. The first was greatly increased gain. This was a big boost compared to TRF tuners, which were strictly limited as far as maximum gain was concerned when using valves (or 'vacuum tubes'). Any attempt to increase the gain over this limit would cause the circuit to oscillate, resulting in a loud squeal.

Second, the selectivity of the superheterodyne was a big improvement over previous circuits and this meant that weak stations could be separated out from strong stations that would otherwise tend to blitz half or more of the tuning dial.

Finally, the superheterodyne receiver brought with it the possibility of automatic volume control (AVC), also known as automatic gain control (AGC), although this did not become a feature until around 1930. AGC did away with the need for manual gain controls and meant that all stations came in with roughly the same loudness, in spite of the fact that some stations may be very strong and some very weak.

Since the advent of the superhet, there have been relatively few changes to the basic circuit configuration until the arrival of software-defined radios (SDRs), although the components used have changed radically over time. Originally, valves ruled, but now transistors are used or even a single integrated circuit with just a few external components.

So if you decide to build this AM superhet receiver, you will be building a circuit configuration which has been around for over 90 years, but one which is still just as relevant today.

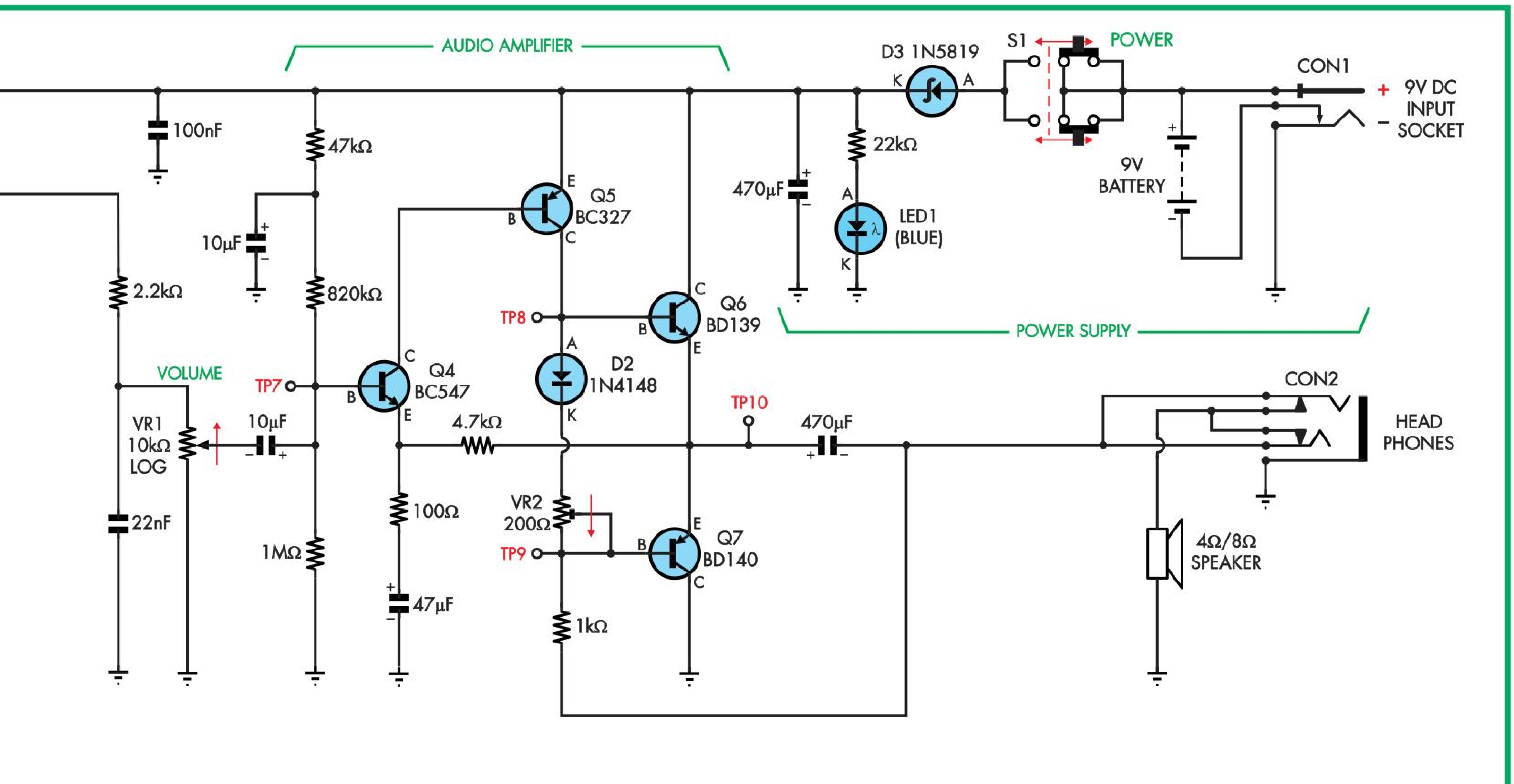


Fig.1 : the *Super-7 Receiver* uses seven commonly available transistors. The incoming RF signal is picked up by the ferrite rod antenna and fed to Q1, which functions as a self-oscillating mixer. The 'difference' signal (between the oscillator and tuned input signal) is then coupled via T2 to the two IF amplifier stages and onto detector diode D1, to recover the audio signal and generate AGC, which is fed back to Q2. The audio signal is then fed, via volume control VR1, to the amplifier stage comprising Q4-Q7.

and Q7. This amplifier is directly coupled throughout, apart from the output capacitor which we'll come to in a moment. Q4 is connected as a common-emitter stage with all its collector current becoming the base current of the following PNP transistor, Q5.

Q5 also forms a common-emitter stage and provides most of the voltage gain of the audio amplifier. Its collector current flows partly into the bases of the push-pull output transistors, Q6 and Q7, while the rest goes through the 1kΩ resistor and loudspeaker to ground.

Output transistors Q6 and Q7 are connected as complementary emitter followers in class-AB mode.

To explain class-AB, this is a variant of class-B operation. In class B, Q6 conducts for one half of the signal waveform, then turns off, and Q7 takes over for the second half of the signal waveform.

This switching process inevitably causes crossover distortion, which can make the sound quality quite unpleasant.

Class-AB fixes this by making sure the transistors never fully turn off.

So the two output transistors are slightly biased into forward conduction by the voltage developed across diode D2 and trimpot VR2. VR2 provides quiescent current adjustment to minimise (but not completely eliminate) crossover distortion.

Negative feedback from the output of the amplifier is provided by the 4.7kΩ resistor to the emitter of Q4. The AC voltage gain of the amplifier is set to about 47 by the 100Ω resistor from the emitter of Q4, while the series 47µF capacitor sets the bass roll off of the amplifier.

Amplifier output with no signal sits at about half supply, ie, around 4.5V. This DC offset is removed by using a 470µF coupling capacitor between the amplifier output and the loudspeaker.

The capacitor allows the AC signal to pass to the loudspeaker but blocks the DC voltage. The DC needs to be blocked to prevent the loudspeaker cone being forced away from its normal resting position and increasing distortion.

By now, you've probably realised that this design aims to achieve good performance without using too many components, similar in concept to a portable AM radio.

For example, the output stage component count has been minimised by connecting the 1kΩ resistor to 0V via the speaker coil.

The same DC bias conditions could have been obtained in the output stage by connecting the 1kΩ resistor directly to the 0V line, but there is a good reason for doing it the way we have.

Bootstrapping

By connecting the 1kΩ resistor via the speaker, we take advantage of the fact that the output stage transistors are emitter followers. In this mode, these transistors have a voltage gain just slightly less than one.

This means that the AC signal voltage at the emitters of Q6 and Q7 (and hence across the speaker) is only slightly less than the signal voltage at the bases of these two transistors. Because of this, the AC voltage applied across the 1kΩ resistor is very small and so little AC current flows.

Hence, transistor Q5 'sees' a much higher collector load than the nominal 1kΩ. This means it is able to provide more drive to the output stage and higher overall voltage gain.

This technique is known as 'bootstrapping' and is commonly used in audio amplifiers. However, while this is an effective method which improves the overall performance, it does have one drawback.

If the loudspeaker or headphone is not in circuit, no current can flow through the 1kΩ resistor. If this happens, the output stage is not biased on and the whole amplifier draws no current at all.

This may not seem important because the speaker will normally always be connected. But if you try to monitor the amplifier without the

Superhet AM Receiver

The fundamental operation of a superheterodyne AM radio receiver (usually abbreviated to 'superhet') is shown in the block diagram below.

There are many variations on this theme, but all rely on the principle of heterodyning, or mixing, different frequencies. Heterodyning is applied in order to provide high gain, without instablility.

The antenna is tuned by a variable capacitor in a parallel resonant circuit.This variable capacitor is one section of a 'ganged' capacitor (ie, two sections on the one shaft or control). The other section of the ganged capacitor varies the local oscillator which we'll come to in a moment.

The parallel resonant circuit is tuned by the variable capacitor so that the wanted signal is selected while signals at other frequencies are rejected. The signal from the antenna is then fed to the mixer and this is where the 'superheterodyne' process takes place,

The word 'heterodyne' refers to the 'beating' effect generated by mixing two signals of different frequencies. 'Hetero' is derived from the Greek word for 'other' while 'dyne' is derived from the Greek word for power. 'Super' here refers to the fact that the second frequency is higher than the frequency of interest.

In the mixer stage, the local oscillator signal is mixed with that from the antenna. The result is a signal with components at four different frequencies: the two original frequencies (ie, the carrier and local oscillator), plus the sum and difference frequencies.

Assuming the carrier and local oscillator frequencies are close together, the sum will be at around twice the tuned frequency while the difference will be at a much lower frequency.

This resulting signal is passed to an amplifier stage (or stages) tuned to the difference frequency, which results in the rejection of signals at the three other frequencies. The difference frequency is referred to as the Intermediate Frequency or IF.

In most radios of this type, the IF is 455kHz or 450kHz. The first superhets had an intermediate frequency of 50kHz which gave very sharp selectivity but poor audio response, because of the necessarily low bandwidth of the IF filters. Later, the standard IF was 175kHz and later still this was standardised at 455kHz.

The output of the IF stage is then applied to the detector, which in transistor radios is usually a germanium diode, selected because of its low forward-voltage drop. (We've used a 'schottky' diode in the Super-7 circuit for the same reason – ie, low voltage drop).

The diode rectifies the IF signal, which is then filtered to remove the RF carrier, leaving the audio signal. This is then fed to the audio amplifier, which drives a loudspeaker.

Automatic gain control

Apart from demodulating the IF signal, the detector is also used to produce the AGC voltage. AGC was seen as a wonderful innovation when it was introduced because it eliminated the need to adjust the set's gain each time you tuned into a new station. Gain adjustment is necessary to stop the IF stages from overloading on strong signals, while still providing sufficient gain for very weak signals (eg, from distant or low-powered stations).

To derive the AGC voltage, the raw DC output from the detector is heavily filtered to remove the audio signal, producing a DC voltage that is proportional to the amplitude of the IF signal.

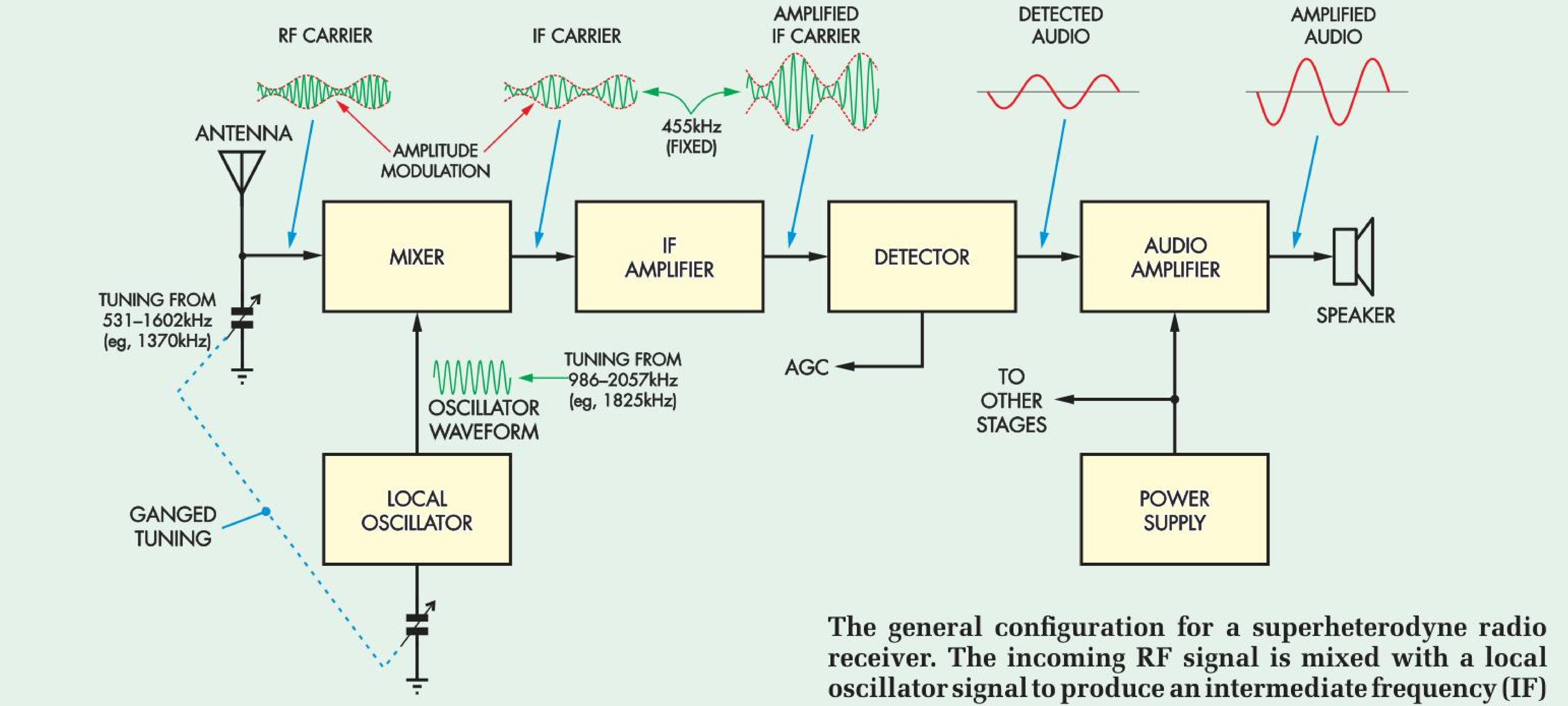
This is then used to control the gain of the IF stages and sometimes also the RF stage, so that the signal is held to a more or less constant level, ie, using negative feedback.

So why 'superheterodyne', rather than 'subheterodyne', ie, with the local oscillator below the station frequency? After all, this would produce the same difference frequency. This was tried but it results in a lower sum frequency component which can be within the broadcast band, resulting in 'ghost stations' (or 'image frequencies') on the dial, at higher frequencies than the actual station. This is pretty much totally eliminated in a superhet.

Local oscillator

The local oscillator frequency always tracks the tuned frequency of the RF amplifier. So for an IF of 455kHz, if the radio is tuned to 1370kHz, the local oscillator will be set to 1825kHz (1370 + 455). Similarly, if the radio is tuned to 702kHz, the local oscillator will be at 1157kHz (702 + 455).

All this happens automatically by virtue of the two-section capacitor tuning gang – one section is for tuning the antenna and the other for the local oscillator. These variable



The general configuration for a superheterodyne radio receiver. The incoming RF signal is mixed with a local oscillator signal to produce an intermediate frequency (IF) signal, which is then fed to a detector stage to recover the original audio signal.

SUPERHETERODYNE RADIO

speaker connected or plug in a bare jack socket into CON2, no current will flow through it and the amplifier won't work. So don't be trapped!

One other little circuit trick needs to be noted before we finish this article, and this involves the 470µF capacitor that connects across the 9V supply.

This relatively large capacitor may seem unnecessary. But since the circuit can be powered from a 9V battery as well as a DC plugpack, it is a requirement. That's because as the battery ages, its internal impedance rises and so it is less able to deliver the relatively high current pulses demanded by the amplifier and the result is more distortion from the amplifier.

capacitors track each other over the adjustment range. Various tricks are used to create the necessary frequency offset while maintaining good tracking.

Variations on a theme

While we have just described the broad concept of the superhet, there are many variations on this theme. For example, many superhet circuits have a tuned RF amplifier stage and some do not have a separate local oscillator. Instead, the local oscillator is combined with the mixer stage in what is known as a self-oscillating mixer or mixer/oscillator (as in the Super-7 circuit).

Others may have two or three IF stages and some may have a separate detector to produce the AGC voltage.

Another important variant is the double conversion configuration used in some high-performance communications receivers. This combines two superhet stages to shift the signal frequency in two ‘steps’, and is usually used for receiving shortwave signals, as these are at much higher frequencies (up to 30MHz) than broadcast AM stations.

The Super-7 circuit is a ‘single conversion’ superhet, meaning that it performs just one conversion from the incoming RF frequency to the intermediate frequency.

Other variations which are common include ‘permeability tuned’ superhets and nowadays, frequency synthesised receivers with digital readouts and microcontroller control.

Permeability tuning was common in car radios, where tuning was done by varying inductance rather than capacitance. One advantage of permeability tuning, especially useful in cars, is reduced susceptibility to vibration.

Regardless of all the variations, you will find that all superhets have the same operating mode and same circuit functions as described by the block diagram above.

By the way, Edwin Armstrong, who invented the AM superhet receiver was the same person who later developed the principles of FM transmission and reception.

One further note before we leave the origins of the superhet: apparently, radio (or ‘wireless’) circuits working along the same principle were used in British submarines during the First World War.

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By placing the 470µF capacitor across the 9V supply, we effectively reduce the AC impedance of the battery and thus enable it to deliver those higher current pulses. The result is better sound quality.

Note that the speaker signal goes via the integral switch in headphone socket CON2, so that if headphones/an earphone is plugged in, the speaker is automatically disconnected.

Note also that the tip and ring connections are wired in parallel, so you will get audio from both sides of stereo headphones/earbuds, even though the AM radio output is mono.

Finally, indicator LED1 shows when the circuit is switched on, via power switch S1 and reverse battery protection diode D3.

D3 is another schottky diode, which means that its very low forward voltage will result in minimum loss from the battery, while still protecting against accidental polarity reversal.

While you can’t permanently fit a 9V battery in the holder the wrong way around, you can certainly make accidental contact the wrong way around.

In the next article, we will show you how to assemble your *Super-7 AM Radio*, including its custom-made case and hand-span dial. We will also describe the alignment procedure.

Parts list – Super-7 AM Radio Receiver

1 double-sided PCB available from the *EPE PCB Service*, coded 06111171, 313 × 142.5mm
1 set of laser-cut acrylic case and dial pieces (SILICON CHIP Online Shop Cat SC4464)
1 AM radio coil pack (T2-T5)
1 mini tuning gang capacitor (VC1-VC4)
1 ferrite rod with coil (T1)
1 100mm (4-inch) 4- or 8-ohm loudspeaker
1 DPDT push-on/push-off switch (S1)
1 round knob for switch S1
1 16mm 10kΩ logarithmic taper potentiometer with 6.35mm D-shaft (VR1)
1 knob to suit VR1
1 2.1 or 2.5mm inner diameter DC socket (CON1)
1 6.35mm stereo switched jack socket (CON2)
1 9V DC 250mA (or higher current) plugpack and/or 9V battery
1 9V PCB battery holder
12 PC stakes
8 M3 tapped 25mm spacers
8 M3 flat washers
8 M3 × 10mm machine screws
4 M3 × 15mm nylon or polycarbonate machine screws
4 100mm cable ties
3 No.4 × 6mm self-tapping screws
4 M3 × 15mm machine screws and nuts (for mounting speaker)
1 150mm length of medium-duty hookup wire
Optional knob to suit the dial

Semiconductors
4 BC547 NPN transistors (Q1-Q4)
1 BC327 PNP transistor (Q5)
1 BD139 NPN transistor (Q6)
1 BD140 PNP transistor (Q7)
1 BAT46 schottky diode (D1)
1 1N4148 diode (D2)
1 1N5819 schottky diode (D3)
1 3mm high brightness blue LED (LED1)

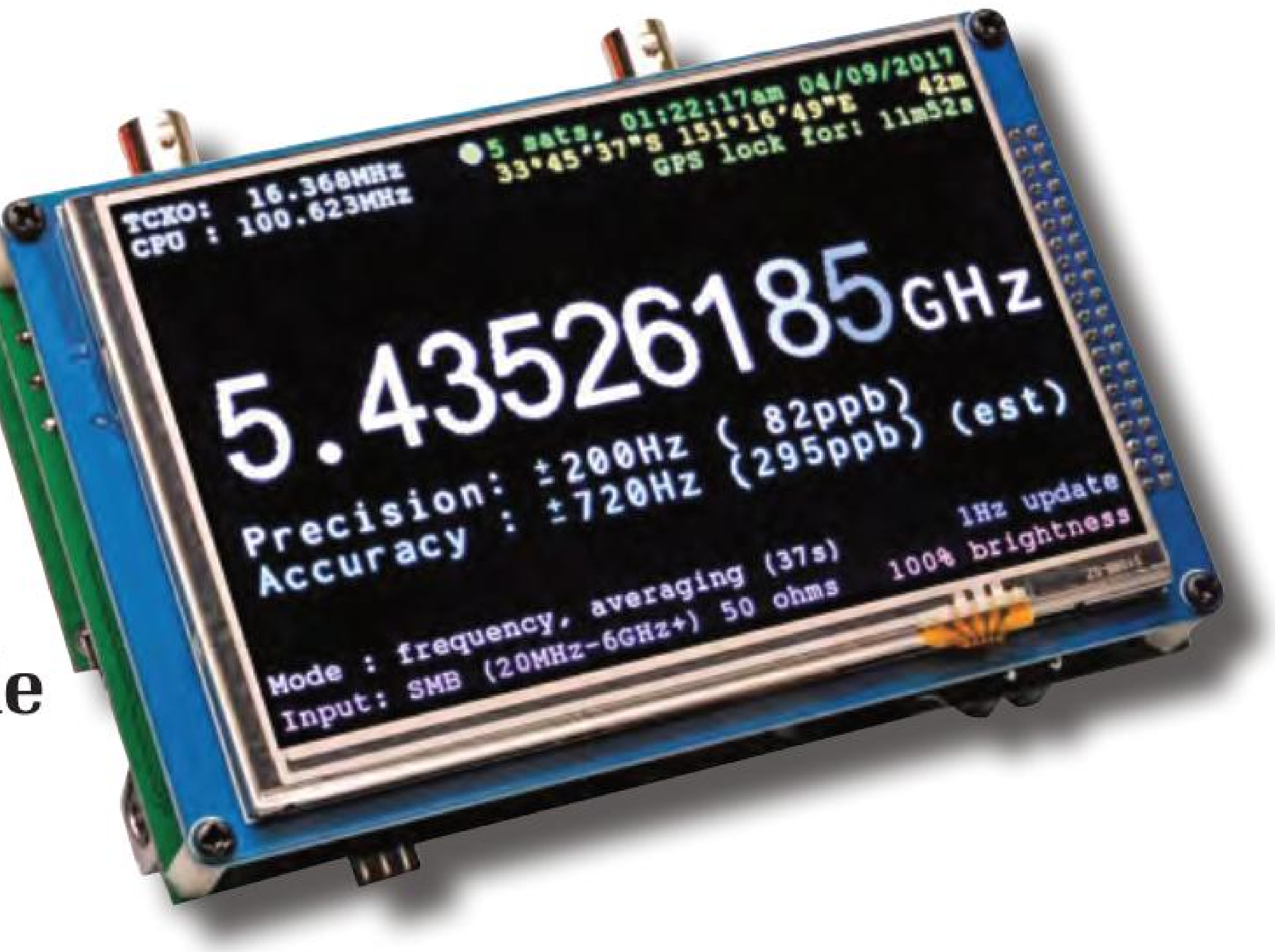
Capacitors
2 470µF 16V PC electrolytic
4 10µF 16V PC electrolytic
1 47nF MKT polyester
1 10nF MKT polyester
1 47µF 16V PC electrolytic
3 100nF ceramic
5 22nF MKT polyester
1 4.7nF MKT polyester

Resistors (0.25W, 1% [***^ 5% carbon OK***])
1 1.2MΩ ^ 1 1MΩ 1 820kΩ 1 56kΩ 1 47kΩ 1 39kΩ 1 27kΩ
1 22kΩ 1 12kΩ 1 10kΩ 1 4.7kΩ 2 3.3kΩ 1 2.2kΩ 2 1kΩ
1 470Ω 2 100Ω 1 200Ω miniature horizontal trimpot (VR2)

6GHz+ Touchscreen Frequency & Period Counter

Part 2

by Nicholas Vinen


TCXO: 16.368MHz
CPU : 100.623MHz
5 sats, 01:22:17am 04/09/2017
33°45'37"S 151°16'49"E 42m
GPS lock for: 11m52s
5.43526185GHz
Precision: ±200Hz (82ppb)
Accuracy : ±720Hz (295ppb) (est)
1Hz update
100% brightness
Mode : frequency, averaging (37s)
Input: SMB (20MHz-6GHz+) 50 ohms

This new *Frequency Counter* has greater bandwidth and more sensitivity than any previously published design, and its large touchscreen display makes using it a breeze. Now we'll describe how to assemble the two PCBs, test them, load the software and put the case together.

If you've read the first article on the *Frequency Counter* last month, you should have an idea of just how good its performance is and also a fairly thorough understanding of how it works.

As the photos in that issue showed, it's built using a PCB populated mainly with surface-mount devices (SMDs), plus a few RF connectors, enabling it to piggybacks onto the Explore 100, which in turn is plugged into a 5-inch full-colour touchscreen LCD panel.

We also showed the rather spiffy-looking laser-cut clear acrylic case that it's housed in on the penultimate page of that article.

So, having explained all that in detail last month, we're now going to go through the assembly procedure. It may seem a little daunting, as you have to build two separate PCBs and then assemble those two plus the pre-built LCD panel into a 'sandwich' before building the box around it.

Actually, besides a couple of fine-pitch SMD ICs, most of the components are relatively easy to work with and the Explore 100 module can be put together in just a couple of hours. The *Frequency Counter* board may take you a little longer, but it isn't too difficult, and a reasonably experienced constructor can probably put it all together and get it working in one day.

Having said that, don't rush it! It's far better to take your time, especially when working with SMDs, rather than risk damaging the PCB or any components.

Even if you stuff something up, it's generally possible to remove it, clean up the board and then try again. The assembly actually lends itself to being done in stages, so you may prefer to spend a couple of hours at a time on it, then stop and move onto the next stage when you're fresh.

Assembly

There are four main steps in putting together the 6GHz *Touchscreen Frequency Counter*. You can do the first two steps in either order: assembling and testing the Micromite Plus Explore 100 module, and assembling the *Frequency Counter* PCB. Once those two are finished, you can plug them together and test the unit as a whole, before assembling the case around it.

With the exception of the 5-inch LCD touchscreen, all the parts for the Explore 100 module are available as a short form kit from **micromite.org**. Note though that assembling this does involve soldering the 100-pin SMD PIC32 microcontroller.

The circuit details of the Explore 100 module were published in the September 2017 issue of *EPE*, while the construction details were given in the October 2017 issue. If you don't have that issue, the process is relatively straightforward.

Briefly, you need to fit SMDs IC1 and Q1 first, being very careful to orient them correctly and ensure that all the fillets are properly formed and no pins are shorted. Then solder the 10µF SMD capacitor in place, near IC1.

Next, install the through-hole components as shown on the PCB silkscreen printing. These consist of nine resistors, 13 ceramic capacitors, two electrolytic capacitors, three LEDs, one crystal, one transistor, one regulator, one tactile switch and numerous connectors. The LED cathodes (shorter leads) go into the holes nearest the adjacent PCB edge.

When fitting the connectors, make sure that CON6 and CON9 are fitted to the underside. You don't need to fit CON1, CON4, CON5, CON7, CON10, CON13, CON14 or the headers for the real-time clock. But if your kit comes with those parts anyway, it certainly won't hurt to install them. We do recommend that you fit JP1 as it will aid in testing.

If you haven't used a pre-programmed PIC32 then the next step is to program it using a PICkit 3 or similar in-circuit serial programming (ICSP) tool. This is done via 6-pin header CON3. Then we suggest you test the board to make sure it's working before fitting the LCD panel.

The easiest way to do this is to connect a USB/serial adaptor to CON6 and then open a terminal emulator, set to the default baud rate of 38400. Make sure the correct COM port for your USB/serial adaptor is selected and then wire up its Tx, Rx and GND pins to the appropriate pins on CON6, making sure to wire Tx to Rx and vice versa.

To power the unit, if your USB/serial adaptor has a 5V output, you can wire this to the bottom-most terminal of JP1 (if fitted). Alternatively, fit a jumper to JP1 and plug a mini USB cable from your PC to CON2.

As soon as the unit has powered up, you should see the Micromite's banner appear on your terminal emulator. If you don't, disconnect power and recheck your wiring and COM port selection. Normal power consumption for the Explore 100 without a screen is around 100mA (at 5V). If yours is well under or over this, something is wrong, so check the PCB carefully for soldering defects and misplaced components.

Assuming you've had success, remove power and plug the LCD screen into CON10, attaching it with four 12mm tapped spacers and eight machine screws. You will then need to power it up and run the following commands on the console, to set up and test the LCD. Note that power consumption will jump to several hundred milliamps.

```
OPTION LCDPANEL SSD1963_5,
   LANDSCAPE, 48
OPTION TOUCH 1, 40, 39
GUI TEST LCDPANEL
```

You should now see coloured circles being drawn on the screen. Press enter in your terminal emulator to stop, then run this command to calibrate the touch sensor:

```
GUI CALIBRATE
```

You will then need to use a thin object that will not scratch the screen, like a toothpick, to carefully press and hold in the centre of the targets which appear in each corner of the screen. Hopefully, you will get a message on the console that says 'Done. No errors'. Otherwise, try calibrating it again. That completes the initial set-up of the Explore 100 module.

Main PCB assembly

There are many more SMDs on this board, plus a few through-hole components. Note though that the lead spacings of the components on the main board are, with one exception, much larger than those of IC1 on the Explore 100. Overall, you should find the components on this main board easier to solder.

The main board which is available from the *EPE PCB Service*, is double-sided, coded 04110171 and measures 134 × 51.5mm. Almost all components are fitted on the top side.

Start with IC4. You can use a standard soldering iron as long as the tip is not too large, but we recommend that you purchase a small tube or syringe of flux paste and some solder wick if you don't already have some. Good light and a magnifier are also important.

Place a small amount of solder on one of the corner pads for IC4 and then orient the part on the board as shown in the PCB overlay diagram, Fig.3. Pin 1 goes towards upper left – this should be indicated on the PCB silkscreen. Once the IC is oriented correctly, heat the solder you applied to the corner pad and then carefully slide the IC into place and remove the heat. This process should take no more than a few seconds.

Now carefully check that the IC pins are centred on their pads. Check all four sides. Use magnification to make sure that all pins are properly centred on their pads. If not, re-heat the solder on that one pad and gently nudge the IC towards the correct position.

Repeat this process until you are happy that the IC is correctly located and check that its pin 1 is in the correct position before tack soldering the diagonally opposite pin. Re-check that all the pins are correctly located; you can re-heat either solder joint at this point to make slight adjustments.

Now apply a thin layer of flux along all the IC pins and then apply solder to all the pins. Make sure you apply enough to get proper fillets. It's difficult to avoid bridging the pins at this point; what's most important is getting the solder to flow onto each pin and pad on the PCB.

Once all the pins have been soldered, apply another thin layer of flux paste and then use a piece of solder wick to remove any excess solder, especially where adjacent pins are bridged. Proceed carefully and re-apply flux paste if necessary.

Once you have finished, clean off the flux residue (using either a proper flux solvent or ethyl alcohol/methylated spirits and a lint-free cloth) and examine the solder joints under good light and magnification to ensure they are all good and there are no more bridges left.

When you have completed soldering IC4, you can fit IC3 in the same manner. IC3 has smaller, more closely-spaced leads but there are only eight of them, four each on two sides of the IC. One additional thing you will have to take into consideration is that IC3 has a thermal pad on the underside and ideally, this should be soldered to the matching pad on the PCB.

If you have a hot air reflow system this is quite easy, as it's just a matter of spreading some solder paste on the nine pads for this IC, putting it in position and then gently heating it until all the solder paste melts and reflows.

If you are just using a regular old soldering iron, you should spread a thin layer of solder paste on the large central pad, then drop the IC down into position and tack solder it in position.

Using the correct screws

Last month, the parts list called for four 6mm M3 machine screws but we found construction a little easier using two 8mm-long machine screws instead. If you can't get these, you can still use 6mm but may need to attach the spacers in a slightly different order. Or as stated in the text, 10mm screws might work.

After checking that its orientation and position are correct, solder the remaining leads using the same technique as for IC4. Then flip the board over and squirt some flux paste into the hole directly under IC3.

Melt some solder into this hole and heat it for several seconds. Remove heat and carefully check that IC3 is hot by quickly touching it with your finger. This indicates that the solder has conducted enough heat through the hole to melt the solder paste you placed under it earlier.

Solder IC7 next. This is in a rather tiny 2 × 1.6mm metal can package but luckily it only has four pads, one in each corner. So soldering it is not that hard but identifying pin 1 requires significant magnification. You should be able to see a dot in one corner of the top surface and this goes to the lower-right pad.

Tin one of the pads and flux the others, then heat the tinned pad while very carefully sliding it into place. Apply a small amount of solder to the other three pads, then refresh the initial one and check with a magnifier that none of the joints is shorted to the can (solder shouldn't stick easily to it).

Note that there is provision for a micro USB power socket on the underside of the board but we haven't tested this and we don't recommend you use it, for two reasons. First, the output voltage of a USB charger is unlikely to be well-regulated and the LCD panel is quite fussy about its power quality. And second, there's the possibility of RF noise getting back into the USB cable and producing a lot of EMI.

Remaining SMDs

The rest of the parts are quite easy to install as they have more widely spaced leads. Solder IC1 and IC2 next, making sure their 'pointy' pins go to the pads marked for pin 1, facing the top edge of the board. Follow with L1 and L2, both of which are in six-pin packages. Their pin 1 dot should be oriented as shown in Fig.3, towards upper left.

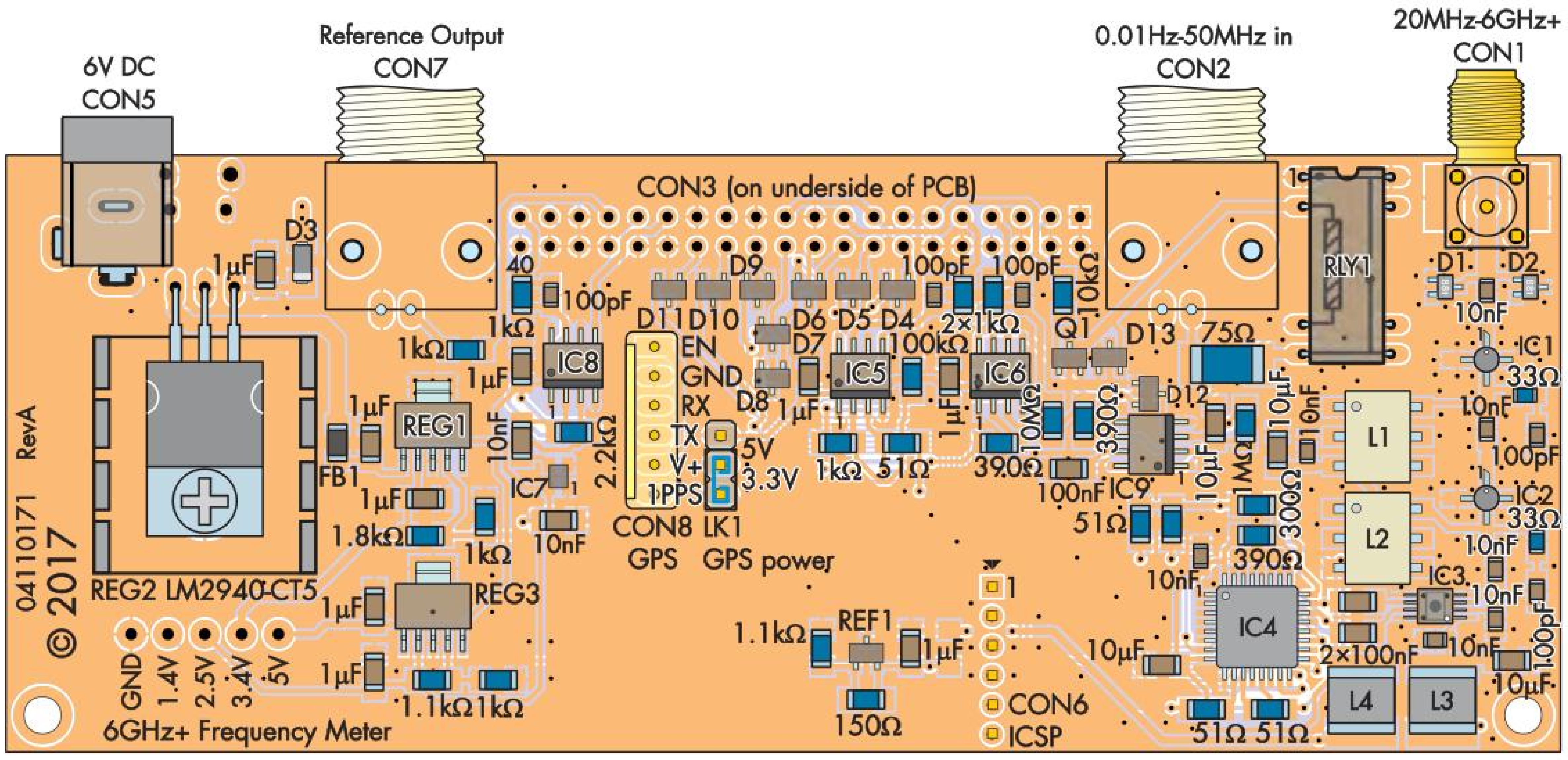


Fig.3: use this PCB overlay diagram for the main *Frequency Counter* board as a guide during assembly. Most of the components are SMDs with the exceptions being RLY1, REG2 and the connectors. It plugs into the Micromite Plus Explore 100 module via CON3, a 2x20-pin female header socket that's mounted on the underside of the board. CON3 and CON6 are the only components fitted to that side of the PCB.

You can then move onto IC5, IC6, IC8 and IC9, which are all in standard 8-pin SOIC packages. These are quite easy to solder. Identify pin 1, indicated by either a dot/divot/logo in the corner or a bevelled edge on that side of the PCB. You can then orient each IC as shown in Fig.3, tack down one pin and solder the others using a similar procedure as before.

Next on the list are regulators REG1 and REG3. These are identical parts, each with one large tab and five smaller pins. The packages have considerable thermal inertia, so spread a thin layer of flux paste on the large pad with a little extra paste on the smaller pads and drop the part in position. Then, tack solder one of the smaller pins (you can pre-tin the pad and heat it while sliding the part into place, if you like, as you did with IC3).

You can clean these joints up with some additional flux paste and an application of solder wick.

Now for the large tab. Apply some solder to this tab and hold your iron in contact with both the regulator tab and PCB pad. You may need to hold it there for some time before the whole assembly heats up enough for the solder to flow down onto the board. Keep adding solder until the tab is covered and looks shiny, then remove the heat.

Inductors L3 and L4 are similarly quite large, so again, spread flux paste on each of their pads before soldering. You can then add some solder to one of the pads and slide the inductor into place while heating that solder.

Again, you may need to wait some time before the inductor heats up enough to slide fully into place and you can then add more solder until a nice, shiny fillet has formed. Let that cool down a little, then solder the opposite end, again waiting until it's hot enough to form a good joint (this should be quicker as both the inductor and PCB will retain significant heat).

The next components on the list are REF1, Q1 and diodes D4-D13. These are all in small 3-pin SOT-23 packages so don't get them mixed up. One of these diodes is a BAT54S (D12) while the others are all BAV99s.

In each case, tack solder one pin, check that the pins are properly aligned, solder the other two pins and then refresh the initial pin. It's easier if you spread a little flux paste on the pads before soldering each part.

Now fit diodes D1 and D2, which are in similar but slightly smaller packages than D4-D11, followed by diode D3, which is in a two-pin rectangular package. Make sure its cathode stripe faces towards REG2 (indicated with a 'k' on the PCB).

You can then fit all the ceramic capacitors and resistors to the board, as well as SMD ferrite bead FB1, where shown in Fig.3. Orientation is not critical for any of these. Note that some of the ceramic capacitors are in slightly smaller 2.0 × 1.2mm packages, compared to the majority of capacitors and resistors which are in 3.2 × 1.6mm packages, but these are not much more difficult to solder.

Also, one of the resistors is a much larger 1W type, but the procedure to mount this one is pretty much the same as the others. It just might take a bit more heat and flux paste.

Through-hole components

With all the SMDs in place, you can now proceed to solder reed relay RLY1 in place. It's in a DIL package, like an IC but without pins in the middle section. Ensure its pin 1 indicator is towards the top of the board, as shown in Fig.3.

Next on the list is REG2 which is in a TO-220 package that's mounted flat on the board with a small flag heatsink. This is important since it needs to deliver several hundred milliamps and it can get quite hot.

Bend its leads down so they fit the pads with its mounting hole correctly located, then place the heatsink underneath and screw the whole assembly firmly to the PCB.

You can then check that the regulator's package is straight before soldering and trimming the three pins. Solder the electrolytic capacitor in next, being careful to feed the longer (+) lead through the hole marked '+' on the PCB, closest to REG2.

The next component to fit is pin header CON3. CON3 is a 40 pin DIL socket (2×20 pins) which is mounted on the underside of the board and plugs into the Explore 100. Make sure it's pushed down fully onto the PCB and nice and straight before soldering, or else you may have trouble plugging it in later. Follow with 6-way standard pin header CON8 and link LK1, both of which go on the top side of the board.

Now mount SMA connector CON1, barrel connector CON5 and BNC sockets CON2 and CON7. In each case, ensure the part is pushed down fully onto the PCB before soldering the pins. The larger metal connectors such as CON1 require quite a bit of heat to form good solder joints.

Note that the pads for CON1 are designed to allow either a right-angle or edge-mounting ('end launch') connector. However, we recommend using a right-angle connector like we did in our prototype so that it lines up with the BNC sockets

Finally, solder CON6 in place. This is a female header socket with long pins. The socket portion goes on the underside of the board, with the pins sticking through the top (see photos). This way, it plugs into the standard header already on the Explore 100 board and allows you to reprogram the PIC32 without having to remove the *Frequency Counter* board. It also helps to hold them together, so don't leave it off.

GPS module wiring

You don't need to connect a GPS module but it improves accuracy and doesn't add terribly to the cost of building the unit, so we expect most constructors will do so. If you're using the recommended VK2828U7G5LF module, it's supplied with a short six-wire cable with a small plug at one end that goes into a socket on the GPS module itself.

The wires are colour coded yellow (enable), black (ground), green (Rx), blue (Tx), red (V_{CC}) and white (1PPS). Crimp and solder these wires to the pins supplied with the 6-way polarised plug, then insert them in the same order as they are listed above.

Because the plug is polarised, you will need to ensure you start inserting them from the correct end of the plug housing. It's simply a matter of lining this housing up with the socket on the PCB, checking which end is labelled EN and then insert the pin soldered to the yellow wire into that end of the plug housing, followed by the others in sequence. Push each one in with a small screwdriver until it clicks into place.

The next step is to select the GPS module operating voltage by bridging two of the three pins on LK1 with a shorting block. For the VK2828U7G5LF, use the 3.3V setting, bridging the pins indicated on Fig.3 or the PCB silkscreen.

This actually powers the module from the 3.4V rail, which is good, since 3.3V is the minimum V_{CC} specification for this module and the extra 0.1V gives us a small safety margin.

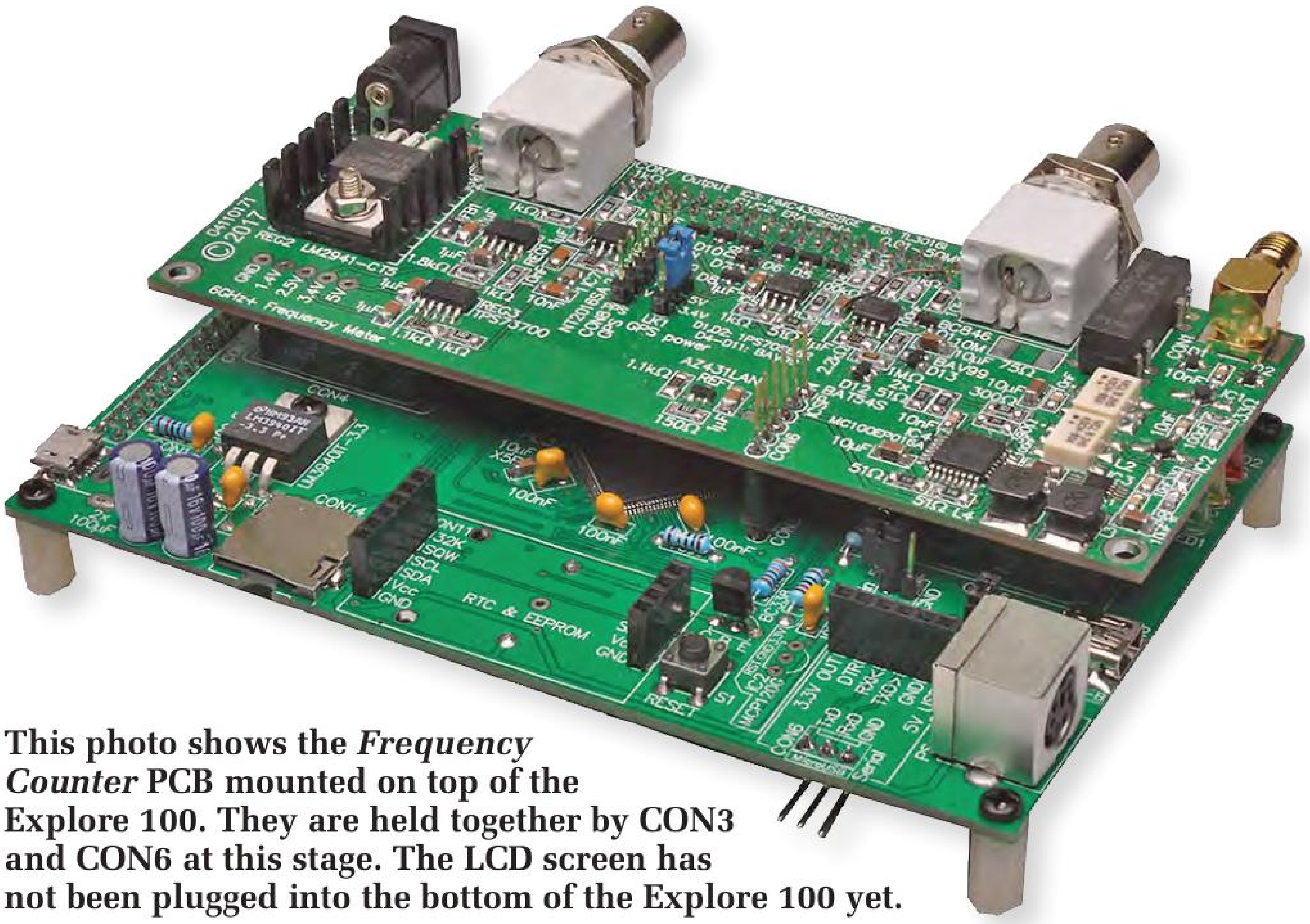
If using a different module, check its data sheet. Most modules will run from either 3.3V or 5V (or both). Make sure your module uses TTL serial signalling at 9600 baud and it will need a 1PPS output to work with this project.

Also, check the data sheet to determine the pinout and route the correct wires to the plug. Some modules may not have an enable pin, or they may allow you to leave the enable pin disconnected for normal operation. The VK2828U7G5LF uses an active-high enable signal, so if your module requires an active-low enable signal, you will have to wire it to GND.

You don't need to plug the GPS unit in straight away; it may be a good idea to check the unit works first, then switch off and plug it in later before checking the GPS-specific functions.

Loading the software

The recommended Explore 100 kit comes with a pre-programmed microcontroller. This is loaded with MMBasic but does not have the BASIC (and C) code required for the frequency counter loaded into it yet. Luckily, since we have already used the serial console to test the unit and set up the LCD, we can use this to load the software into the chip too.



This photo shows the *Frequency Counter* PCB mounted on top of the Explore 100. They are held together by CON3 and CON6 at this stage. The LCD screen has not been plugged into the bottom of the Explore 100 yet.

The easiest way to do this is to download the free MMEdit software which is specifically designed to interface with Micromites. This will run on Windows or Linux machines and is available from **www.c-com.com.au/MMedit.htm**

As well as downloading and installing this program, you will also need to download the BASIC code from the *EPE* website. This is a ZIP package download which includes the MMBasic code (.bas), CFUNCTION source code and HEX file for the *6GHz+ Touchscreen Frequency Counter*. (The latest beta version of MMBasic is also included in the download package.)

Do read the included text file for important notes, including why we're using a beta version of MMBasic and some minor hardware changes we've found are necessary to improve operation when measuring higher frequencies.

Extract the .BAS file and open it in MMEdit. Open the Advanced menu and make sure the 'Auto crunch on load' option is selected. You then need to set up the COM port. Make sure you've closed the terminal emulator you were using before, to free up the port, then select the 'New...' option in the Connect menu and select the relevant port. Set the baud rate to the default of 38,400.

You can then click on the 'Load and run current code' button which is the right-most button in the toolbar at the top of the window, with an icon that looks like a blue stick figure running while holding a torch.

You should then see a progress dialog and the upload will take a minute or so. If it fails, close this window and re-check the COM port settings.

Once the upload is complete, the MMChat console window will automatically appear. Type 'OPTION AUTORUN ON' into the text entry window at the top and press enter. This will cause the software to run each time power is applied.

You can then type 'RUN' to start it. However, it will not work properly yet because the *Frequency Counter* board has not been plugged in. This will allow you to check that the software has been loaded, though.

Initial testing

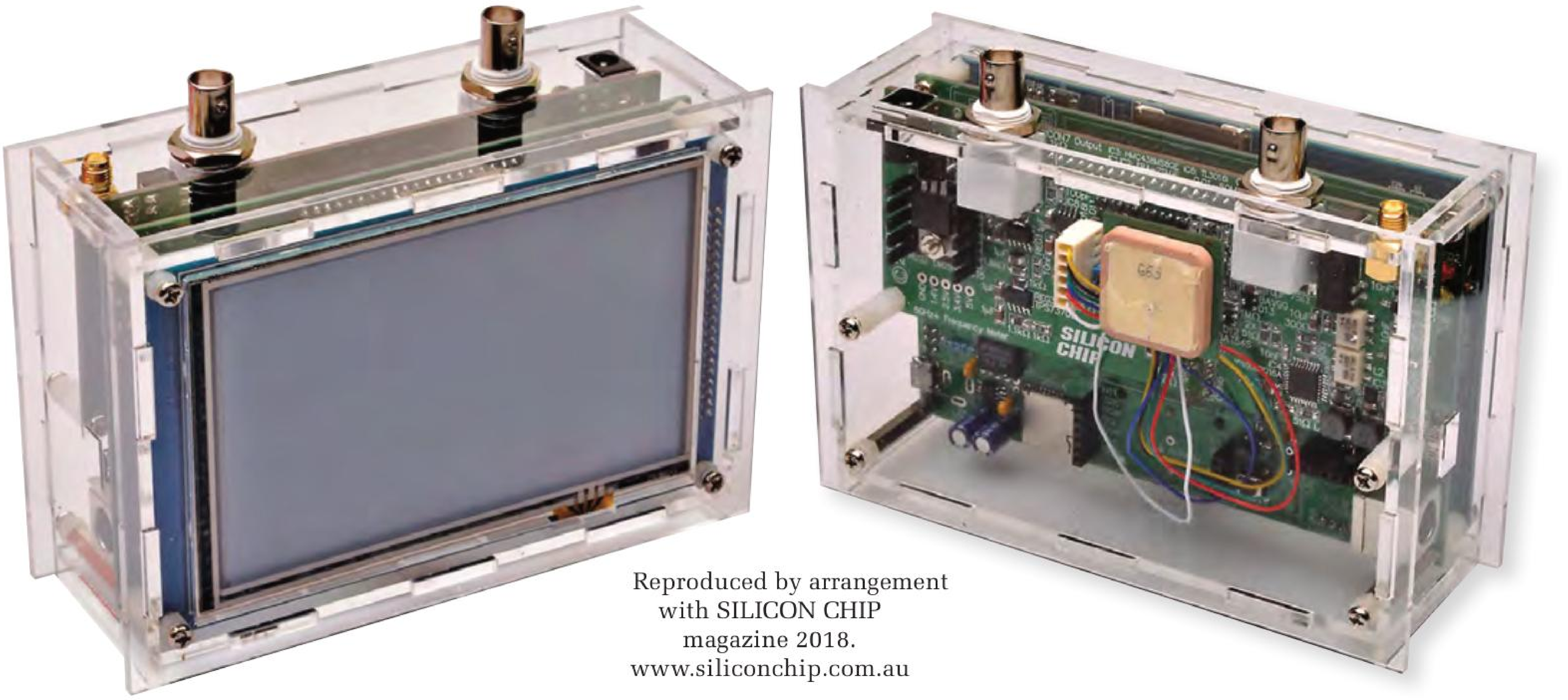
Before plugging the *Frequency Counter* PCB into the Explore 100 (which by now you should have tested on its own), do some basic checks to the *Frequency Counter* add-on board. The first check is to measure the power consumption and check that all the supply rails are within the expected ranges. It's best to perform these checks with the GPS module initially disconnected.

The expected current drain for this board by itself is around 500mA, so if you have a bench supply, set its current limit somewhere between 500mA and 1A. If you don't have a bench supply, connect a DMM set to measure amps in series with a 6V DC regulated plugpack. If that's too hard, you can simply skip this step and just check the voltages.

With power applied, connect a DMM set to measure volts between the GND and 5V test points at lower left. You should get a reading between 4.8V and 5.2V. If it's outside that range, switch off and check for faults.

A much lower reading suggests a short circuit or an incorrectly oriented component somewhere on the PCB (eg, D3) while a higher reading should not be possible and suggests that REG2 has failed.

Now measure between GND and the 3.4V test point. You should get a reading between 3.3V and 3.45V. Again, a low reading would suggest a short circuit, most likely associated with IC1, IC2 or IC4, but could also be caused by a problem with REG1 or one of its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(Left) The LCD screen fits through a large rectangular cut-out in the front of the case, sitting almost flush with its surface. A notch in this cut-out is provided for the ribbon cable at lower right. You can also clearly see how the top panel of the case is recessed to give access to the power, input and output connectors. (Right) This rear view of the completed unit shows how the case is put together. Both the front and rear panels are attached to two points at the bottom of the Explore 100 PCB.

associated components. A high reading would suggest a fault with REG1.

The reading at the 2.5V test point should be in the range of 2.475-2.575V, with a low reading likely indicating a soldering fault with IC7, the temperature-controlled crystal oscillator. A high reading would indicate a likely fault with REG3.

The measurement at the 1.4V test point should be around 1.41-1.44V, with a low reading suggesting a problem with the 300Ω and 390Ω resistors located just above IC4 or one of the components surrounding REF1. A high reading suggests a fault with REF1 itself, or a soldering problem with it or one of the adjacent resistors.

Assuming that all checks out, you can power it down and plug the GPS module back in (assuming you're using one). Make sure LK1 is set properly, power the unit back up and check that the power consumption has only gone up by about 50mA and that the 5V and 3.4V rails have not dropped significantly, which would indicate a wiring problem with the module.

You can now power down the PCB and plug it into the Explore 100 board. Make sure to power the whole assembly through the DC power socket on the *Frequency Meter* board, since the regulator on the Explore 100 is unlikely to cope with the extra current drawn by the combination.

More advanced testing

It's probably a good idea to put the unit through its paces now before it's in the case. While you can quite easily change the software once it's in the case (eg, if a bug is discovered or there's an upgrade), fixing any hardware issues would probably require you to partly disassemble the case. It wouldn't be a disaster but it's easier to test it at this stage.

The first thing to do is power it up and check that the display comes up and updates properly. Power consumption of the complete unit should be very close to 1A, so verify that if you can. Then check the upper-left hand corner of the screen and make sure that you have a sensible TCXO frequency reading (close to 16.368MHz).

If you have a GPS unit fitted, you should be able to see the reflection of its status LEDs at the rear of the unit. For the VK2828U7G5LF, red indicates power and green flashes indicate satellite lock. Place the unit where it has a good view of the sky (eg, on a windowsill) and wait a few minutes.

You should see green flashes from the GPS unit and the top-right corner of the screen will update to show the time, date, number of satellites, your location and give a flashing green circle pulsing at 1Hz, in time with the 1pps signal from the GPS unit.

You can now connect a signal source with a known frequency to the two inputs at the left side of the unit and verify that you get sensible readings. That will verify that pretty much all the functions of the unit are working properly. We'll go into more details of the software operation next month.

Case assembly

The case is made up of six pieces of clear 3mm laser-cut acrylic, forming the front, back, top, bottom and side panels. Peel off the protective coating from each piece as you assemble the case. You will need to remove the screws from both ends of each space between the Explore 100 board and the LCD panel before you can proceed. Use Fig.4 as a guide to help you with the following assembly procedure.

Start with the front panel, which has the large cut-out for the LCD. Try to avoid bending it too much since it could potentially snap. This has a small notch for the LCD ribbon cable to fit through, so figure out which way around it goes using this notch.

Now feed a 32mm M3 machine screw through one of the two lower corner holes in the front of the panel and do up a nylon hex nut tight, holding the screw in place. Repeat for the other lower corner. Attach 10mm machine screws to the other two (top) mounting holes in a similar manner and hold in place using nylon nuts.

Now unplug the LCD from the Explore 100 and feed the screen through the hole on this panel, then screw the original 12mm spacers onto each screw shaft until it's holding the LCD in place firmly in all four corners. You can then plug the Explore 100 board back into the LCD panel after feeding the protruding screw shafts through its mounting holes.

Use two 8mm machine screws to attach it to the two top spacers and screw two nylon hex nuts onto the two remaining screw shafts after placing nylon washers under each. Do them up tightly.

Next, feed two 6mm or 8mm M3 machine screws through the two mounting holes on the main *Frequency Counter* board from the underside

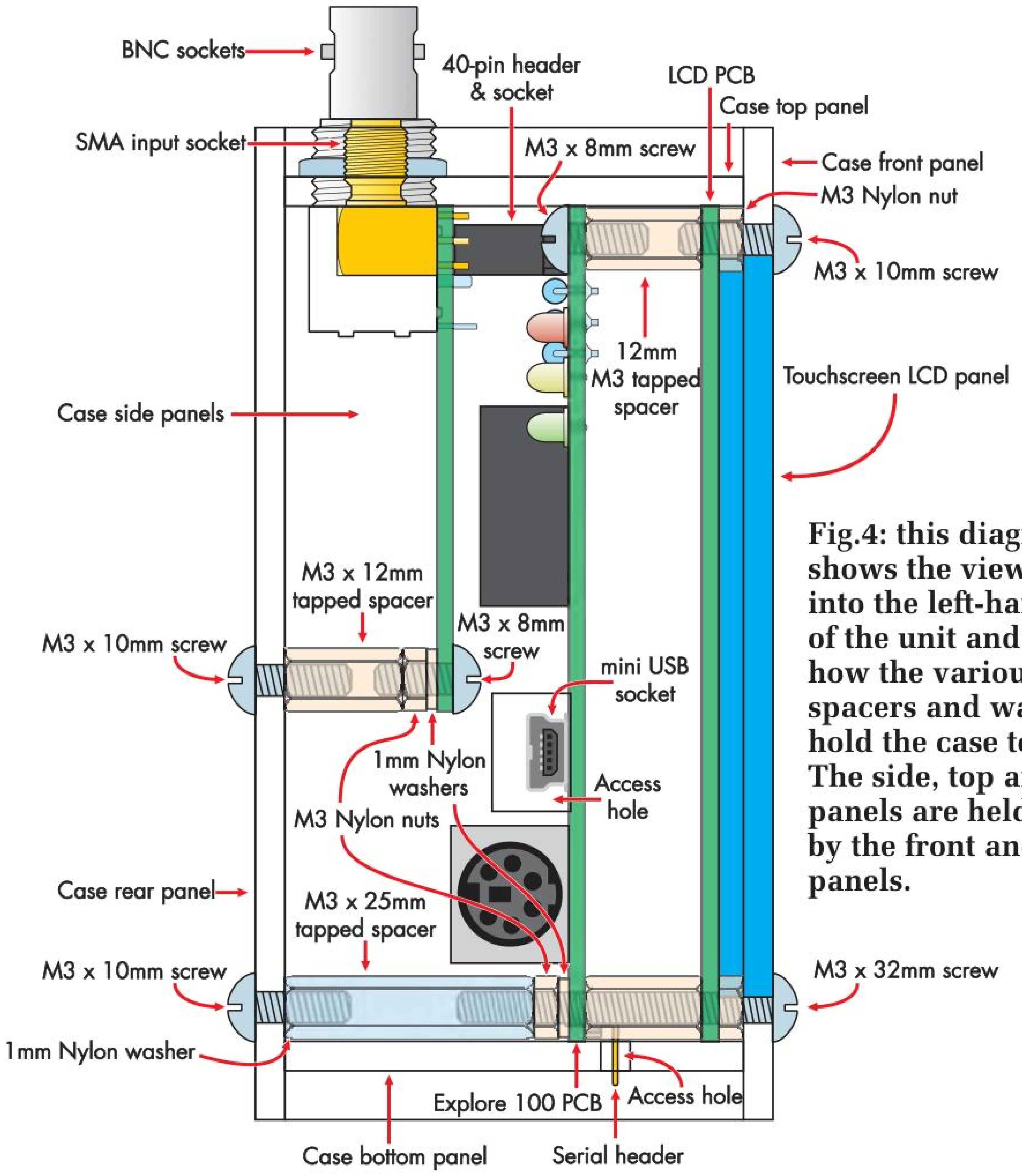
BNC sockets
40-pin header & socket
LCD PCB
Case top panel
SMA input socket
M3 x 8mm screw
Case front panel
M3 Nylon nut
M3 x 10mm screw
12mm M3 tapped spacer
Touchscreen LCD panel
Case side panels
M3 x 12mm tapped spacer
M3 x 8mm screw
M3 x 10mm screw
mini USB socket
1mm Nylon washers
Access hole
M3 Nylon nuts
Case rear panel
M3 x 25mm tapped spacer
M3 x 10mm screw
M3 x 32mm screw
1mm Nylon washer
Explore 100 PCB
Access hole
Case bottom panel
Serial header

Fig.4: this diagram shows the view looking into the left-hand side of the unit and clarifies how the various screws, spacers and washers hold the case together. The side, top and bottom panels are held in place by the front and rear panels.

and attach them using nylon nuts and washers, done up well.

Note that if you can't get 8mm machine screws, you may be able to get away with 10mm screws. You can also use 6mm screws (which are also commonly available) but you may need to reverse the order of spacers in the last step.

The next step is to feed the two 25mm tapped spacers over the screw shafts in the lower part of the assembly. Once those are done up, you can place the rear panel on top of the spacers and check that the 3mm holes line up properly.

If you're wiring up the GPS module, now is a good time to attach it to the rear panel using double-sided tape and plug it into its header. There should be just enough room in the case with the rear panel fitted for the connector.

Make sure you tape the GPS receiver in a position where it won't foul any other components. We recommend that it's fitted near the top of the case for better signal reception.

Now remove the nuts and washers from the BNC connectors and then slot the tabs of the top panel into the front and rear panels. Do the BNC connector nuts back up loosely (with the washers underneath) to hold the top panel in place. The bottom panel is held in similarly, between the front and rear panels. Orient it so that the small cut-out gives access to the serial header pins.

Now it's just a matter of slotting the left and right panels into the holes in the front and rear panels and over the tabs on the top and bottom panels. The only difference between the left and right panels is that the left panel has a cut-out to access the mini USB socket.

With all the panels in place, feed the four 10mm M3 machine screws through the holes in the rear panel and do them up loosely. Then, having checked that all panels are properly positioned, do them up properly and tighten up the BNC socket nuts.

Next month

In the final instalment, we will explain how to use the *Frequency Counter* .

Micromite parts and competition!

We recommend you make **micromite.org** your first port of call when shopping for all Micromite project components. Phil Boyce, who runs micromite.org, can supply kits, programmed ICs, PCBs and many of the sensors and other devices mentioned in recent articles.

Last, but not least, do see page 24 for an exciting Micromite competition!

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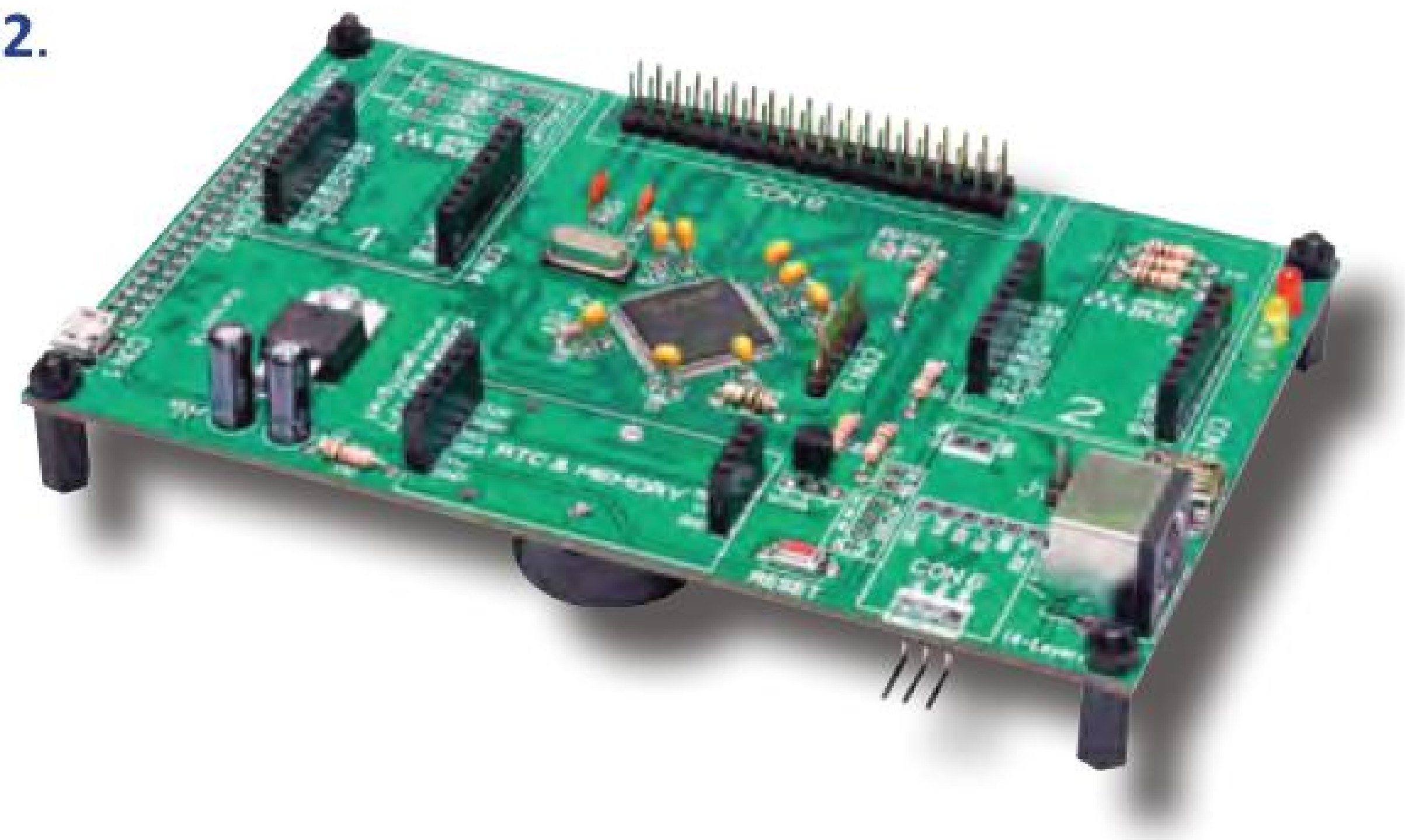
To enter, simply send an email to **epe@micromite.org** with the email subject as: **6GHz2**.



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The system consists of a generic socketcard, on which the AVR device is inserted, and a device-specific signal routing card, which routes the signals from the socket pins to the different functions on the STK600 main board, dependent on the device. This design simplifies hardware setup when switching from one AVR device to another.

The kit offers access to all device pins, and several useful hardware functions such as pushbuttons, LEDs and dataflash to create a complete system for prototyping and testing new designs. Free Atmel Studio IDE lets designers write and compile firmware in either assembly or C language, and download the code to the target AVR device.

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This is, of course, impossible!

Design by
Allan Linton-Smith

High-performance Dipole Loudspeaker

This loudspeaker, intended for smaller homes and apartments, will really challenge your assumptions about speaker cabinet design. In fact, it has *no* cabinet – and yet it is a wide-range design with a frequency response from 20Hz to 18kHz. To pinch a phrase from *The Hitchhiker's Guide to the Galaxy*, 'This is, of course, impossible!'. But as Arthur Dent and Ford Prefect discovered, even the impossible *can* work, albeit (in this case) with the aid of electronic skull-duggery (and perhaps the ultimate answer: 42)!*

More than a year ago, when this project was first mooted, we were very disparaging, making comments like, 'Stupid, impractical idea!', 'It could not possibly produce any useful bass!' and some others which cannot be published.

Since then, there have been a number of prototypes produced and the electronic skull-duggery has been refined. Now the results are quite impressive: real, wide-range high quality sound from a loudspeaker system with no cabinet at all, as can be seen in the photos.

But why would anyone want to build a loudspeaker system without a cabinet? Well, why not? Cabinets can be hard to make and they can have unwanted resonances. It turns out that there are a number of manufacturers around the world who do produce some weird and wonderful dipole loudspeaker systems. But to purchase them you'll need to pay top dollar – we have seen prices from £10,000 to, wait for it, £2,000,000!

Our Dipole Loudspeaker costs *dramatically* less than even the lower figure – and can be built by any electronic enthusiast. You don't even need the wood-working skills a normal speaker cabinet would demand.

In essence, it is just a large timber baffle with three loudspeakers mounted on it: a Celestion horn tweeter and two 10-inch woofers from Altronics.

And the electronic skull-duggery?

Well, this is an active (powered) loudspeaker system, with three power amplifiers and the *3-way Active Crossover* featured in the September and October 2018 issues of *EPE*.

The suggested power amplifiers are the *SC200* (135W into 8Ω) designs (described in January, February and March 2018) and the 10W per channel *Tiny Tim Stereo Amplifier* (described in the January, February and March 2015 issues).

Why such a huge disparity in the power outputs? We use the *Active Crossover* to provide lots of bass boost to the woofer, hence the 135W amplifier, while the midrange and horn tweeter can be driven to more than adequate levels with both channels of the *Tiny Tim Stereo Amplifier* .

That's a brief overview of the concept, so now let's discuss the development of the *Dipole Loudspeaker*.

Development

The designer, Allan Linton-Smith, has been developing the dipole loudspeaker concept over a number of years and had produced some reasonably promising systems, but these had always been rejected by us as being much too 'thin' in the bass department.

Bass is the real stumbling block, of course. After all, with no cabinet, there is nothing to prevent the out-of-phase output from the rear of the woofer from cancelling the output from the front of the woofer. In fact, the overall bass response will be mainly determined by the dimensions of the baffle board on which the woofer is mounted.

Some extremely expensive dipole loudspeakers attempt to overcome this problem by using multiple woofers and huge bass drive power, but in the end, there are definite limits.

Allan Linton-Smith soon found that bass boosters only made things worse by creating reasonable bass but a very distorted lower mid-range. Not only was their performance simply not up to scratch, but also these experimental systems used some very expensive drivers with very impressive specs. These would have been largely unobtainable and/or beyond the budget of the average DIY speaker builder.

Then he tried a commercial 3-way active crossover system and that enabled some reasonable progress to be made. This involved using one 10-inch woofer from Altronics (Cat C3026) to cover the low bass frequencies at 100Hz and below.

A second, identical woofer was then used to cover the range from 100Hz to 2kHz. Finally, he used the well-tried Celestion CDX1-1730 and Celestion T5134 horn to cover frequencies from 2kHz upwards.

This is where the first problem arose, because there is a huge disparity between the efficiencies of the Celestion tweeter and the Altronics woofer: 110dB/1W@1m compared with 93dB/1W@1m.

Clearly the power amplifier for the tweeter only needs to provide one or two watts. In fact, the tweeter's output needs to be attenuated by about 17dB to match the sensitivity of the Altronics 10-inch driver used as the midrange unit, and it can also be driven to reasonable levels from a 10W amplifier such as the *Tiny Tim*.

*Above all, DON'T PANIC! Only those who have heard the original BBC radio play *The Hitchhiker's Guide to the Galaxy*, by Douglas Adams, or read the book, or even seen the TV series or the movie (all with the same name) will have the slightest idea what these obscure references are all about, especially the famous answer, '42'!

So, what has 42 ('the answer to the ultimate question of life, the universe and everything') got to do with anything? The tweeter sensitivity is 42dB below the woofer, of course! (*Hitchhiker's Guide* graphic on opposite page courtesy: **http://hitchhikers.wikia.com/wiki/Earth**).

If money is no object, you could consider a pair of these Australian-made 'Kyron Gaia' dipole speakers. Each one weighs about 200kg and is made to order by Adelaide-based Kyron Audio. They might look pretty cool, but be prepared to fork out around two hundred thousand pounds. (If that's a bit too much for you, their 3-way 'Kyron Kronos' model will set you back just £75,000).

If you really wanted to go all out, try the Swedish 'Transmission Audio Ultra' system. They're reputed to be one of the most expensive speakers in the world – at about £1m EACH!

But to get bass response to match the levels from the midrange and attenuated tweeter, the second 10-inch Altronics driver needs to be boosted by a whopping 25dB. To do that you need a big amplifier and an active crossover with attenuation slopes of 24dB/octave – which the *3-way Active Crossover* is designed to provide.

OK, leaving aside the need for all this electronic augmentation, are there any advantages in a dipole system? Well, some people apparently like them because of their subjectively 'light, airy and smooth sound'. (Does that mean weak bass?)

Another stated advantage is that dipole loudspeakers are 'neighbour friendly' because high bass pressures are not created in a listening room and therefore heavy bass signals are not transmitted next door or through the floor – a distinct advantage in flats or apartments where thumping bass can be a major cause of complaint!

So does this mean that no real bass is apparent in the listening room? What you will tend to notice is that there are no pronounced standing waves in the room, compared to the sound from a bass-reflex or sealed enclosure.

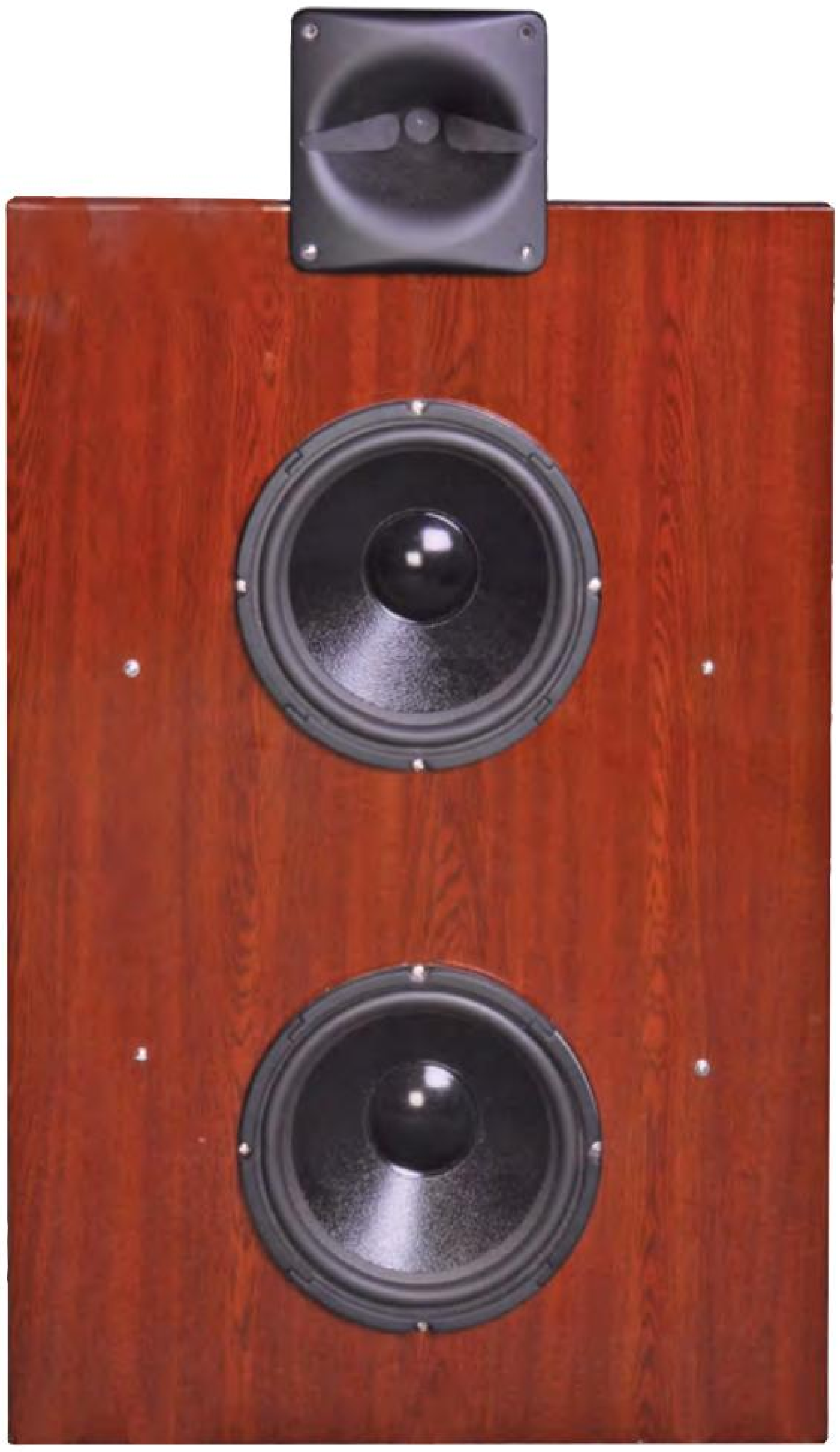
And don't think that because there is no cabinet, just a straight baffle, that most of the sound will be cancelled. If that were true, there would be virtually no sound produced by a loudspeaker suspended in air with no baffle. Clearly, that is not the case and you can easily verify that for yourself. However, the bass will be weak. So bass frequencies below about 100Hz will need a significant boost in power, as noted above.

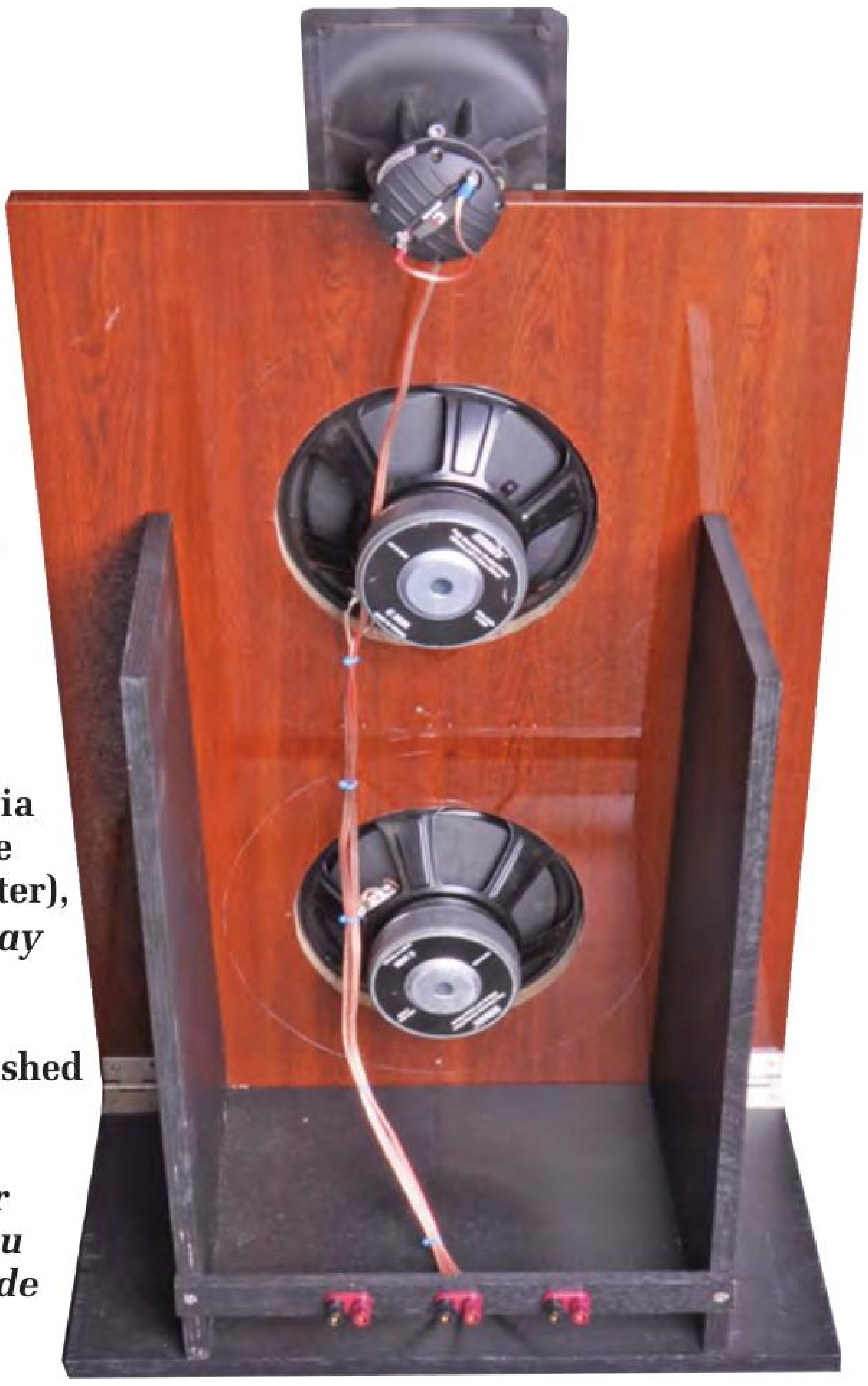
Actual performance

As you can see from the frequency response diagrams, this *Dipole Loudspeaker* system is good from 20Hz to 18kHz ±5dB, which is really remarkable when you realise that we are using off-the-shelf drivers! We should state though that it cannot deliver this very good bass response in large rooms – the amount of power needed would simply overload and burn out the woofer.

In fact, we are relying on the Bass Limiter in the *3-way Active Crossover* to prevent the power amplifier and woofer from being over-driven on loud music passages.

Overall, we were very surprised that a speaker which is virtually 'boxless' can produce such impressive bass and which sounded so smooth!





Front and rear views of the final *Dipole Loudspeakers*. As you can see, the woofer and midrange (actually the same drivers – Altronics/ Redback C3026) are mounted to the 'baffle' in the conventional way, while the tweeter, a Celestion CDX1-1730 matched to a T5134 horn, is simply screwed to the top of the same sheet of timber. While the woofer and midrange are identical, they handle different frequency ranges, fed to them via the three sets of terminals at the back (one pair feeding the tweeter), all under the control of the *3-way Active Crossover*.

The side supports/base were finished with matte black spray paint.

Note: if you'd prefer not to mar the front panel with screws, you could screw'n'glue the base, side panels and front panel with appropriately placed cleats.

We listened in a furnished room of 5 × 5.4 metres at a distance of about three metres and the bass proved quite substantial. But when we stepped outside the direct listening area, the bass was noticeably reduced.

And of course, there is an advantage when using an active crossover, in that the listener can play around with both the crossover frequencies and the amplitudes of the signals fed to the drivers. Everyone had a slightly different opinion of how it should sound and this pretty much depended on the program material.

Construction

We'll look at the base and side supports first, because these are less obvious and can be cut from a variety of timber. We used marine ply – because we had some – but you could use just about any 18mm-thick ply, MDF or chipboard. (Don't use anything thinner because it will not support the baffle properly).

If you don't happen to have suitable timber then there is an advantage in buying a single 2400 × 1200 × 18mm sheet of material because this gives you much more timber than you'll need and we found it to be significantly cheaper than two sheets of 1220 × 620 × 18mm, so you'll have plenty left over for another project.

Parts List – per speaker

2	250mm (10-inch) woofers (Altronics/Redback C-3026)
1	Tweeter driver (Celestion CDX1-1730)
1	Tweeter horn (Celestion T5134)
1	580 × 864 × 18mm baffle, material and finish your choice
1	18mm plywood sheet 610 x 1220mm (or one sheet 2400 × 1200 – does two)
8	12mm × 8g round head screws [for mounting woofers] (or 30mm M4 screws, nuts and washers – see text)
8	30mm × 8g csk head wood screws [for side panels]
14	12mm × 8g stainless csk head wood screws [tweeter/hinges]
2	85mm stainless hinges
3	polarised binding posts (eg Altronics P9257A)
	2.5m heavy duty figure-8 cable (with polarity trace/colour)
	Cable ties, black spray paint

A cutting diagram is shown for 1220 × 620mm but this could be easily transcribed to the larger sheet. Even though there are only a few pieces to cut, accuracy is important because you need the pieces to fit together well.

If you are a competent woodworker with a saw bench you should have no problem cutting the pieces – *but*, if you doubt your skills we recommend having it cut professionally (most kitchen cabinet makers will do this for a reasonable cost) and this will make assembly much easier.

If doing it yourself, cut out one speaker at a time to save you correcting any errors twice!

The side supports are screwed to the base using M4 countersunk head (CSK) stainless steel woodscrews. The side supports can be centred on lines 100mm in from each edge, (see drilling diagram overleaf). Four screws are used for each side support, with the base countersunk to suit.

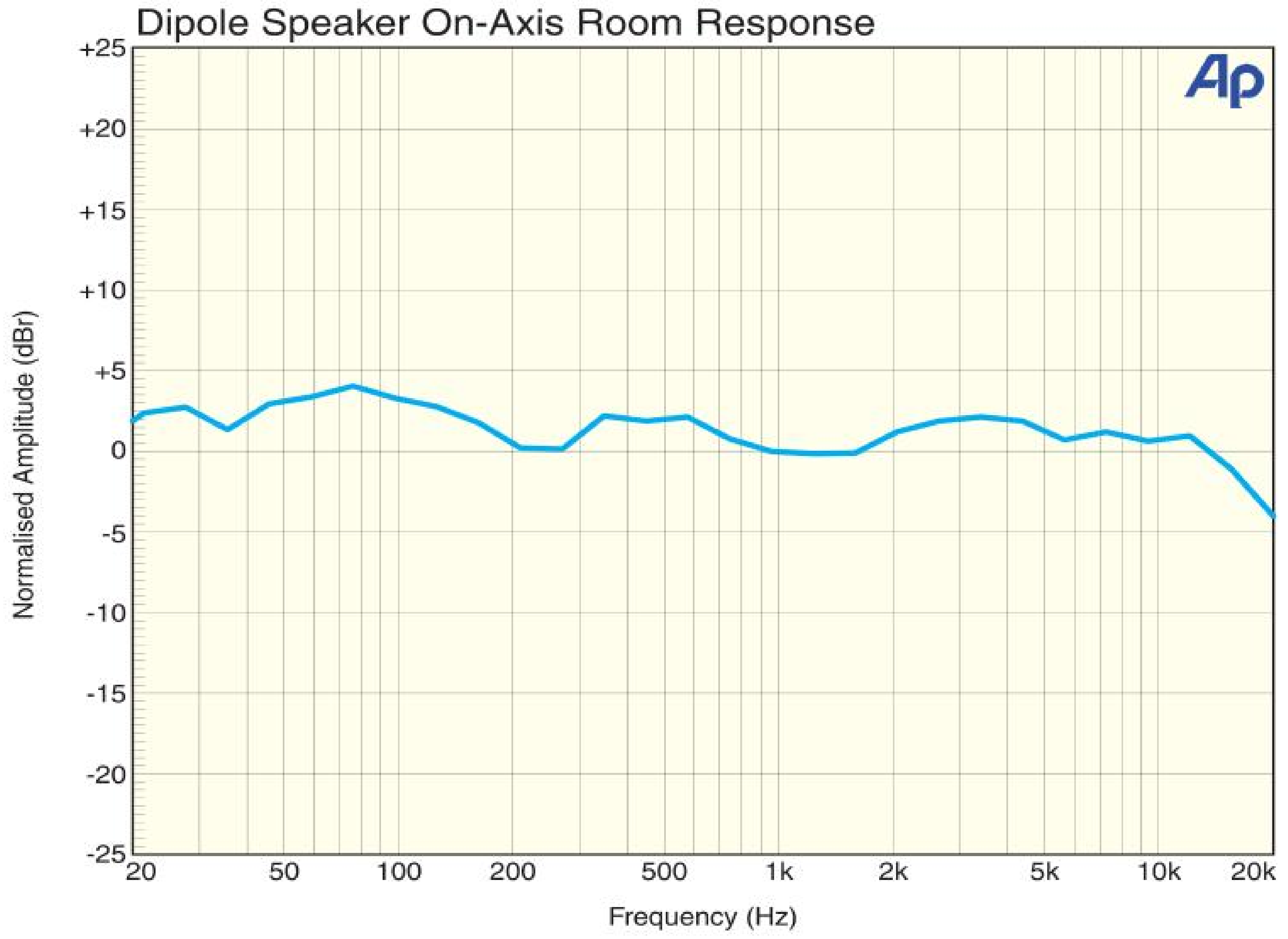
A narrow brace (380mm × 50mm) is cut and screwed between the two side panels to support the three stereo binding posts.

We sprayed the side supports, base and brace with matte black paint for an improved appearance.

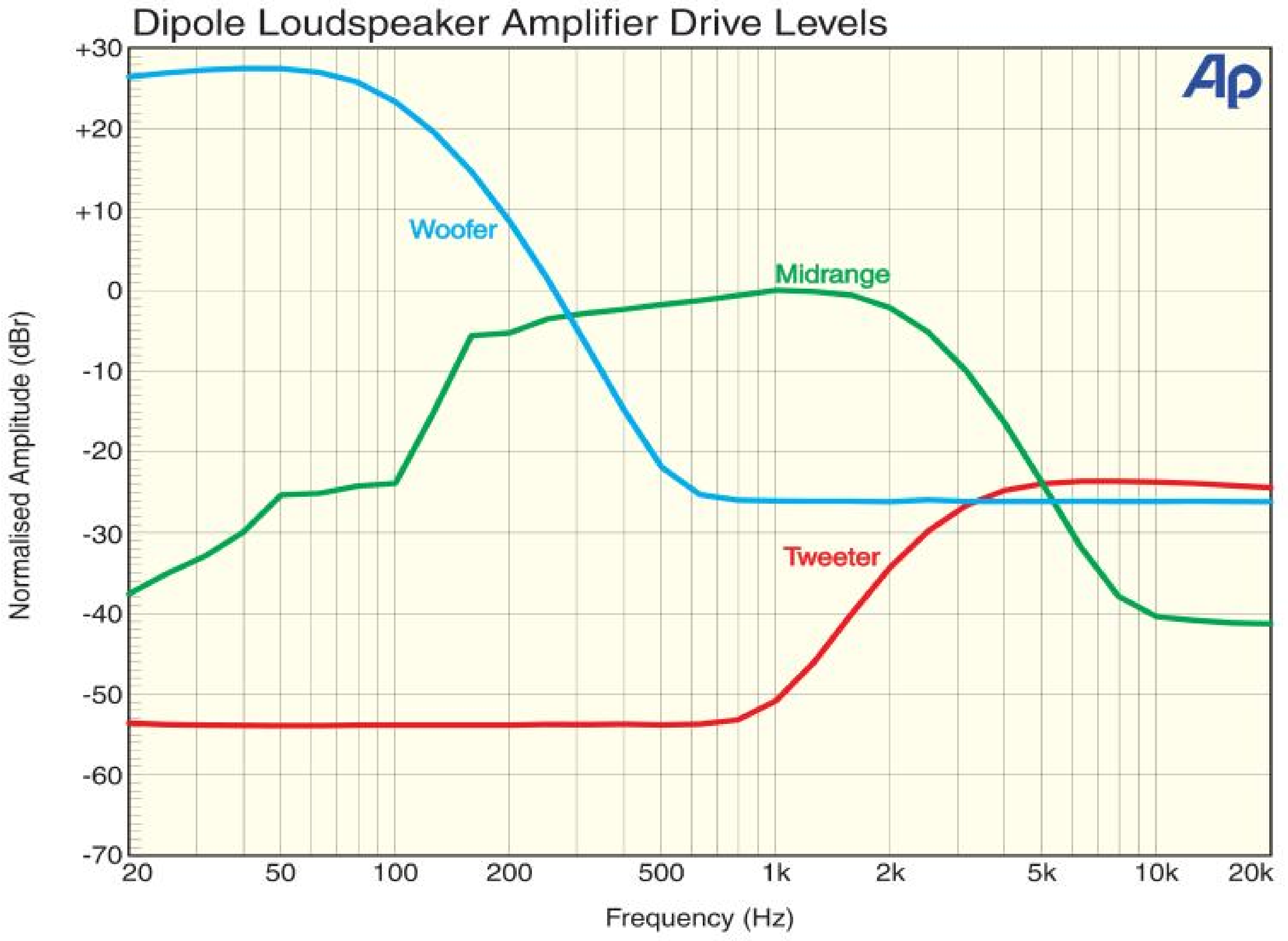
The Baffle

We used a 560 × 864 × 18mm panel from a kitchen cabinet supplier as a baffle. These are available in a variety of colours and finishes and save us having to paint or otherwise prepare and finish it. Do be careful with the surface: they mark very easily if you aren't careful. Leave the protective plastic on the panels until you are finished working with them. Naturally, you'll only need two of these panels because there are no box sides, tops, bottoms or backs to worry about.

Carefully cut the woofer and midrange holes (233mm) as shown in our baffle diagram – a circle-cutting router makes the neatest cut, but if you have to, you could use a jig saw, or drill a series of small holes (say 6mm) inside the required areas and finish off with a rasp or wood file.



Overall 'room response' of the speaker, as measured with a microphone placed directly in front. It's remarkably flat, with just a slight dip above 12kHz; there is no detectable bass roll-off.



Ampltiude of signals being delivered to each driver with a constant amplitude sweep tone fed into the *Active Crossover*. Note the large difference between the peak woofer and the tweeter power.

Cutting (and drilling) from behind results in less chipping on the front. And remember that old adage: measure twice, cut once!

While you're about it, drill the 4mm holes through the baffle which will hold your side panels in place. The drilling guide (below right) shows their position.

But as an afterthought, we imagine many people would prefer not to have the side panel screws going through the polished wooden baffle.

You could instead use small (say 20 × 20mm) cleats screwed and glued to the panels on the rear side to hold them in place. These would be placed on the inside of the side panels.

If you're going to paint the side panels and base (we sprayed them matte black) now is a good time to do it so that the paint can dry.

Hinges hold it together

Rather than screw the base to the baffle we simply used a pair of 85mm stainless steel hinges to join them. This also allows the correct angle (8°) between the pair when the two side panels are fitted.

You will need an extra pair of hands to hold the baffle against the base when marking the hole positions. Drill all 4mm holes (6 per hinge) to, say, 12mm deep – use the old trick of putting some masking tape around the drill bit (12mm from the pointy end) to ensure you don't go too deep.

Again, using an extra pair of hands, align a side panel with the holes you drilled in the base and the baffle and once happy with the location, screw it in position – then repeat for the other side panel.

Placing the speaker drivers in position

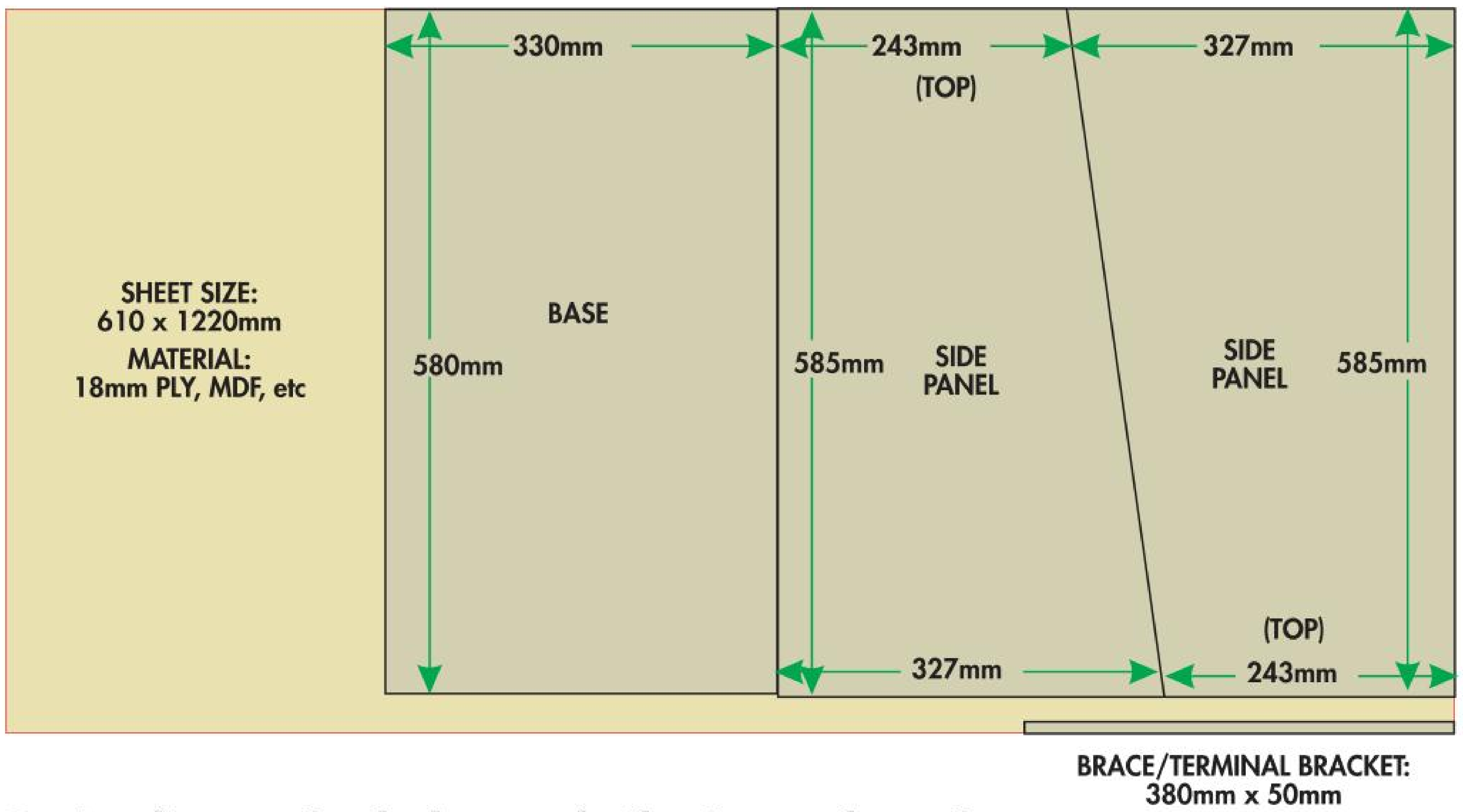
If you are happy with the way your dipole speaker 'box' looks, you can mount the three speaker drivers.

Start with the two 10-inch drivers. These mount from the front of the baffle. Whether you use 12mm woodscrews or 20mm screws with nuts (ie, right through the baffle) is entirely up to you. You can see the heads of either from the front – so black screwheads will look the best.

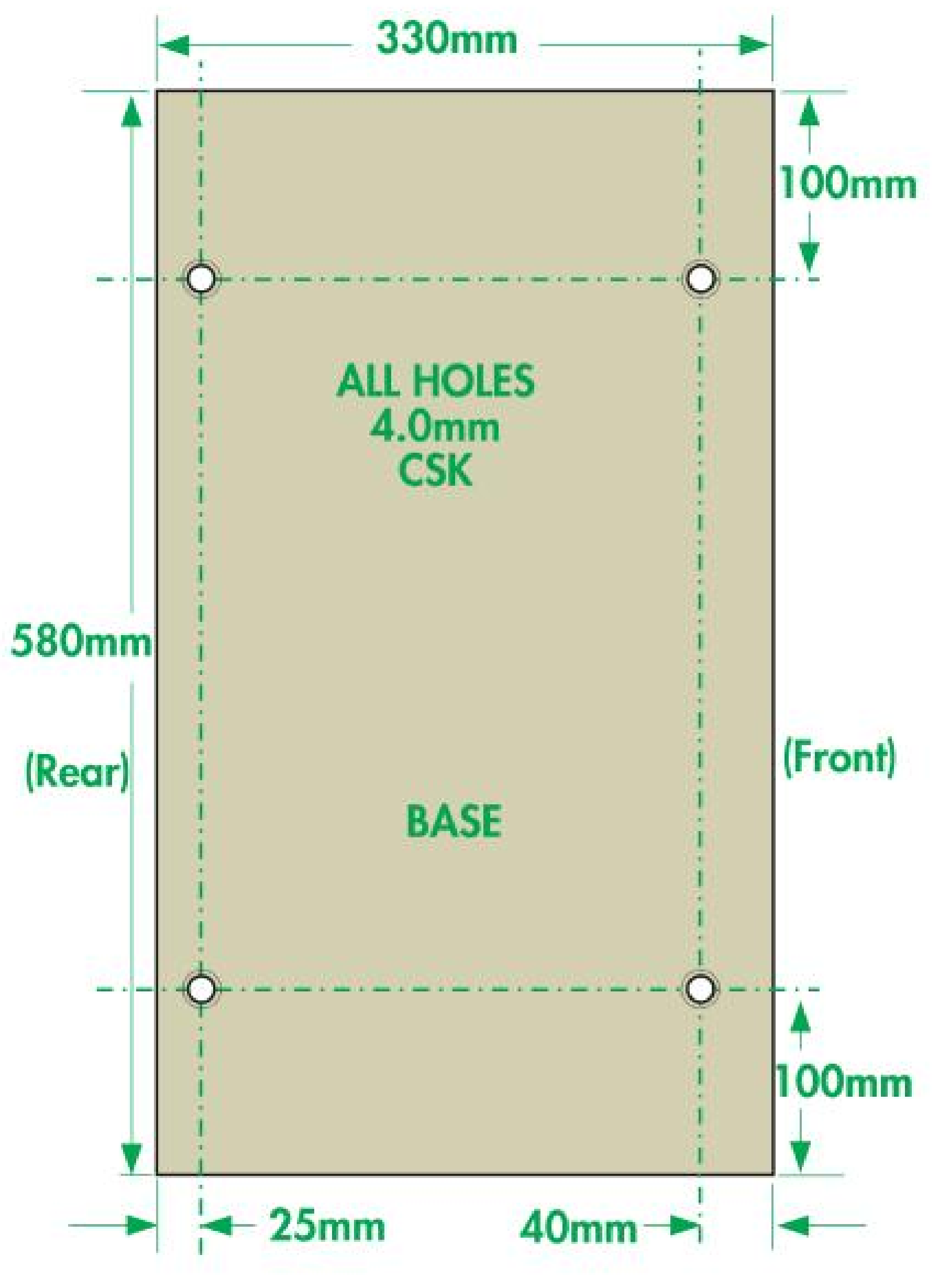
In either case, place the driver in its 233mm-diameter hole and mark the mounting hole positions (eg, with a felt-tipped pen). Remove the driver (don't be tempted to drill the holes in situ!) and then drill either 3mm pilot holes (for woodscrews) or 4mm mounting holes (for screws and nuts).

Repeat for the other driver before mounting the speakers and (carefully!) placing and tightening the screws (or screws and nuts).

Attach the tweeter driver to its horn, place the assembly against the top edge of the baffle and mark the screw holes.



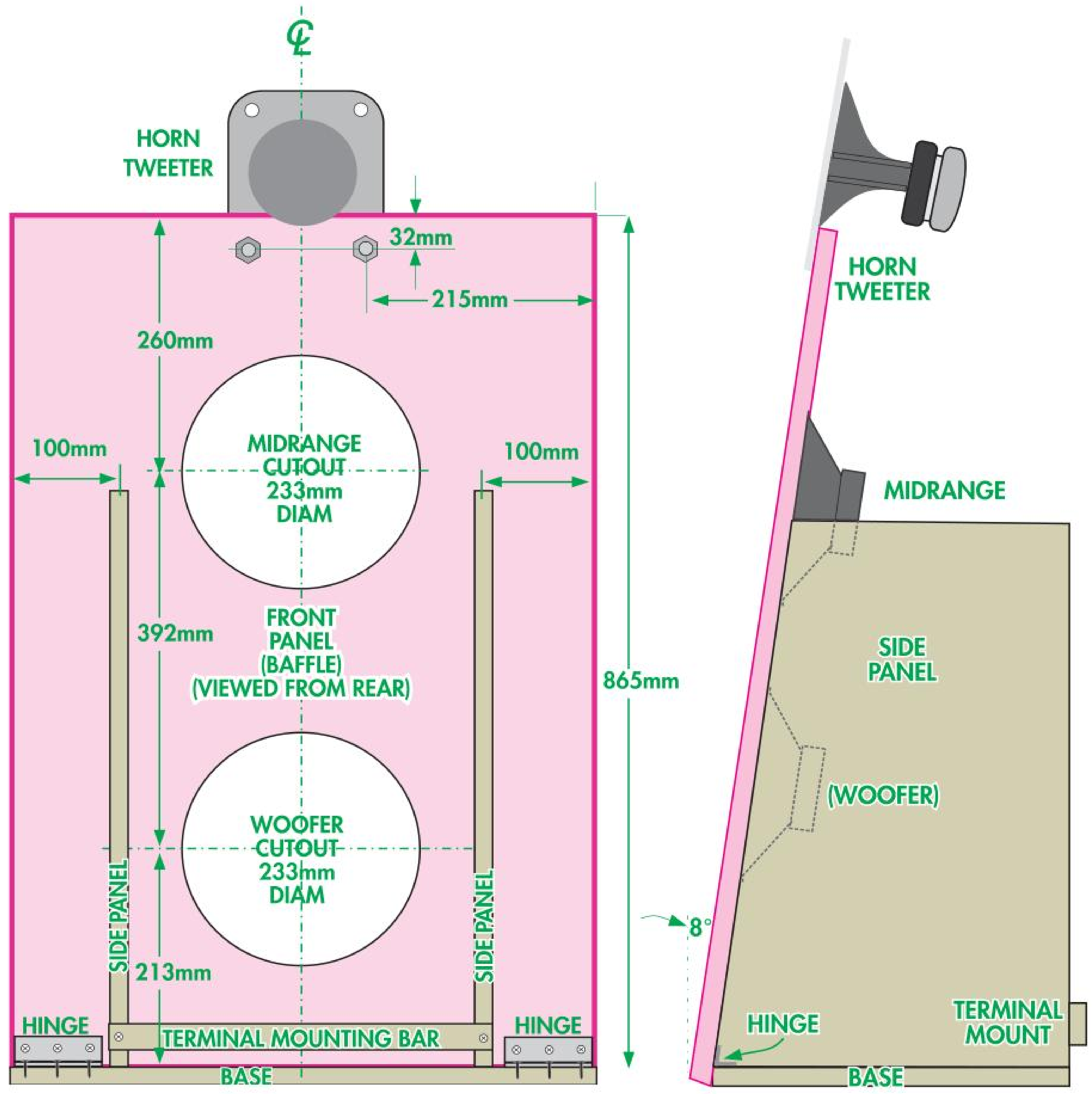
Cutting diagram for the base and sides from a sheet of 18mm ply. Further investigation showed a 2400 × 1200mm sheet of craftwood will cost significantly less and you'll have a lot left over for other projects!



There are only four holes to drill in the base – these accommodate the side panels as shown overleaf.

Again, it's your choice whether you use woodscrews or screws and nuts, but as it's only held in with two screws, we'd be more inclined to use the latter – say 4mm × 20mm.

Remove the tweeter/horn before drilling the two mounting holes, then screw the tweeter/horn firmly into position. We used some weather stripping between the horn and baffle to damp any possible vibration; you could also use silicone or a strip of rubber – anything that will break the metal to panel connection.



℄
HORN TWEETER
32mm
215mm
260mm
100mm
MIDRANGE CUTOUT 233mm DIAM
100mm
392mm
FRONT PANEL (BAFFLE) (VIEWED FROM REAR)
865mm
WOOFER CUTOUT 233mm DIAM
SIDE PANEL
SIDE PANEL
213mm
HINGE
TERMINAL MOUNTING BAR
HINGE
BASE
HORN TWEETER
MIDRANGE
SIDE PANEL
(WOOFER)
8°
HINGE
TERMINAL MOUNT
BASE

Wiring it up

Before screwing the terminal mounting bar to the side hinges (where positioning isn't at all critical), drill the holes required to accommodate the three polarised binding posts.

Each requires a pair of 13mm holes at 19mm centres – again, while overall positioning isn't important, it will look much better to have one on the centre line and the other two equidistant apart – say about 75mm each.

Once done, and with the binding posts firmly mounted, screw the bar to the two side panels, as shown above.

We've specified 2.5m of heavy duty figure-8 cable per assembled speaker. Realistically, only the woofer needs heavy duty cable (remember we're going to pump up to 135W into it!) but there's not too much point in using different cables for the other two drivers.

By the way, we're not specifying 'monster cable' or other marketing cons – just polarised, garden-variety figure-8.

You'll only need about 400mm to wire in the woofer, about 600mm for the midrange and about 1000mm for the tweeter. This is being generous, allowing the three cables to be neatly laced together with small cable ties.

When wiring, watch the polarity: the red terminal should always go to the + speaker terminals and black for the – one (regardless of what colours your wires actually are!).

While any terminal can be wired to any speaker, it makes sense to go in the same order as the drivers: left to the woofer, centre for the midrange and right to the tweeter.

That way, there won't be any errors when you connect your amplifier. (You could also attach some small labels).

Lace together the three cables with some small cable ties – you might also wish to anchor the cable sets to a cabinet side panel, but that's up to you.

Sanity check

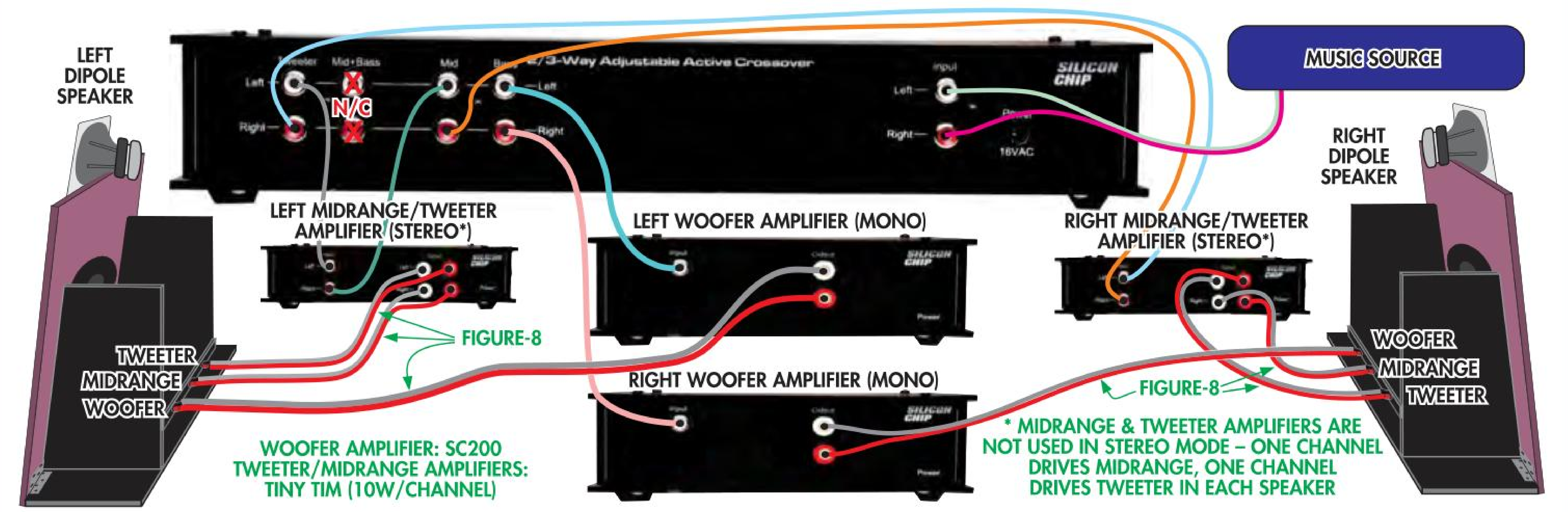
Just to make sure nothing is amiss, give your finished speaker the once over: make sure the wiring is correct; that there are no rattles or movement. Pick the whole thing up (with two people?) and give it a good shake! If it all checks out, repeat the above steps to put together the second speaker.

Checking it out

Even without three amplifiers and the *Active Crossover*, you can check that there are no resonances or buzzes by feeding the woofer with a reasonably beefy amplifier (at least 50W), playing some good, bassy music (did someone mention Toccata and Fugue in D Minor on a pipe organ?) or even a signal generator feeding it 20-100Hz.

And finally

Final wiring up is simple: connect your music source to the *Active Crossover*, take the three *Active Crossover* outputs (bass, midrange and treble) to your *SC200* (bass) and *Tiny Tim* (tweeter and treble) amplifiers and take their outputs



LEFT DIPOLE SPEAKER
Tweeter
Mid+Bass
Mid
Bass
2/3-Way Adjustable Active Crossover
Left
Right
N/C
Input
SILICON CHIP
Power
16VAC
MUSIC SOURCE
RIGHT DIPOLE SPEAKER
LEFT MIDRANGE/TWEETER AMPLIFIER (STEREO*)
LEFT WOOFER AMPLIFIER (MONO)
RIGHT MIDRANGE/TWEETER AMPLIFIER (STEREO*)
TWEETER
MIDRANGE
WOOFER
FIGURE-8
RIGHT WOOFER AMPLIFIER (MONO)
FIGURE-8
WOOFER
MIDRANGE
TWEETER
WOOFER AMPLIFIER: SC200
TWEETER/MIDRANGE AMPLIFIERS: TINY TIM (10W/CHANNEL)
* MIDRANGE & TWEETER AMPLIFIERS ARE NOT USED IN STEREO MODE – ONE CHANNEL DRIVES MIDRANGE, ONE CHANNEL DRIVES TWEETER IN EACH SPEAKER

Wiring the *Dipole Speaker* pair requires a little more attention to detail than a 'normal' loudspeaker setup. Here we're using two *Tiny Tim Stereo Amplifiers* to drive the midranges and tweeters and two (mono) 135W *SC200* amplifiers to drive the woofers. Note the unusual connections to the *Tiny Tims* – we're actually using them as two mono amplifiers.

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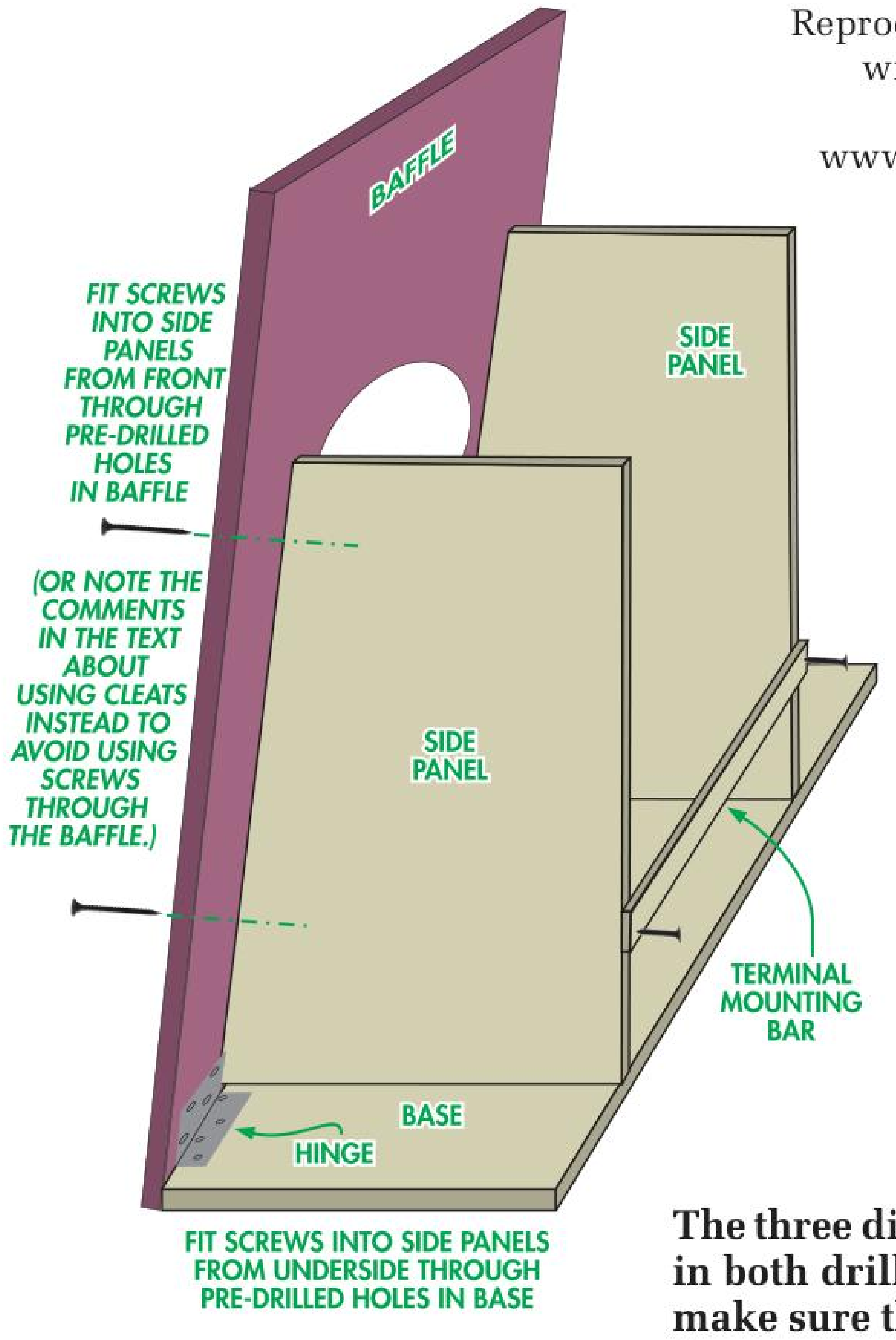
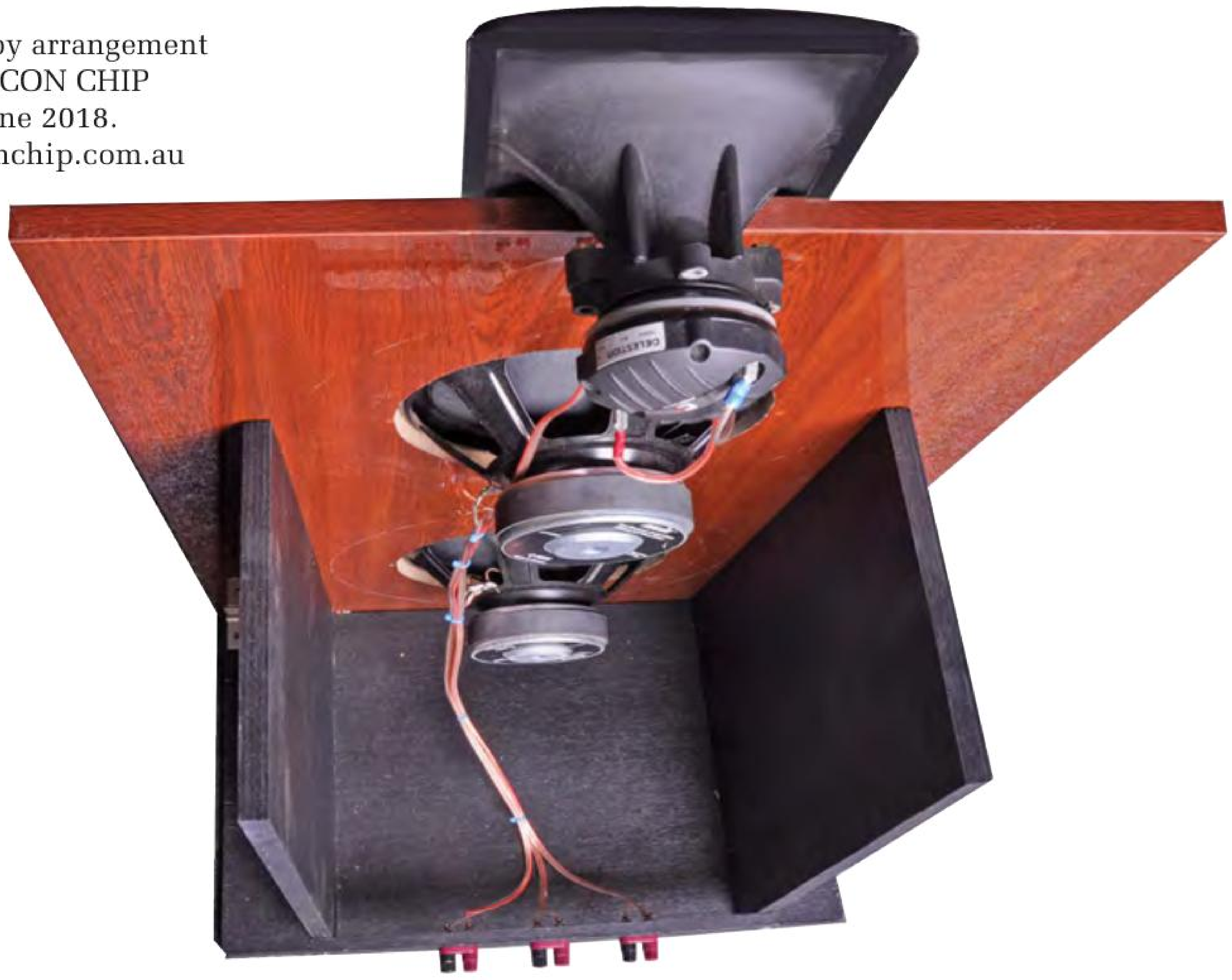

BAFFLE
FIT SCREWS INTO SIDE PANELS FROM FRONT THROUGH PRE-DRILLED HOLES IN BAFFLE
(OR NOTE THE COMMENTS IN THE TEXT ABOUT USING CLEATS INSTEAD TO AVOID USING SCREWS THROUGH THE BAFFLE.)
SIDE PANEL
SIDE PANEL
TERMINAL MOUNTING BAR
BASE
HINGE
FIT SCREWS INTO SIDE PANELS FROM UNDERSIDE THROUGH PRE-DRILLED HOLES IN BASE



The three diagrams above and opposite, along with the photograph above, should assist you in both drilling and assembling the *Dipole Speakers*. It's relatively straightforward – just make sure the panel cuts are true and they mate well with each other. While we didn't find it necessary, you could use some wood glue between the base and side panels.

to the appropriate *Dipole Speaker* terminals, as shown in the connection diagram below.

Some adjustment of the *Active Crossover* controls to suit your particular tastes may be required – but having total control is what it's all about! As a start, aim for:

Lower crossover: 100Hz
Upper crossover: 2kHz
Woofer gain: 0dB (ie, maximum)
Midrange gain: 25dB below woofer
Tweeter gain: 42dB below woofer

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HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£350
HP6632B	PSU 0-20V 0-5A	£195
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HP8341A	Synthesised Sweep Generator 10MHZ-20GHZ	£2,000
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HP8484A	Power Sensor 0.01-18GHZ 3nW-10uW	£75
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Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B with	6910 Power Meter	£295
Tektronix TDS3052B/C	Oscilloscope 500MHZ 2.5GS/S	£1,500
Tektronix TDS3032	Oscilloscope 300MHZ 2.5GS/S	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHZ 1.25GS/S	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHZ 100MS/S	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHZ	£600
Farnell AP60/50	PSU 0-60V 0-50A 1KW Switch Mode	£195
Farnell H60/50	PSU 0-60V 0-50A	£500
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell LF1	Sine/sq Oscillator 10HZ-1MHZ	£45
Racal 1991	Counter/Timer 160MHZ 9 Digit	£150
Racal 2101	Counter 20GHZ LED	£295
Racal 9300	True RMS Millivoltmeter 5HZ-20MHZ etc	£45
Racal 9300B	As 9300	£75
Fluke 97	Scopemeter 2 Channel 50MHZ 25MS/S	£75
Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
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Software Define Radio

Banggood's £16 100kHz-1.7GHz build-it-yourself SDR kit

Review by JIM ROWE

This low-cost Software-Defined Radio uses a standard DVB-T USB dongle to provide wide-range radio coverage from 100kHz to 1.7GHz. How do they manage it at such low cost? It turns out that they use a 'direct sampling' approach which eliminates some of the circuitry which would otherwise be required. So how good is it? Read on...

Remember the clever SiDRADIO project to receive DRM30 broadcasts (October 2014 to January 2015)? There was a limit to what we could cover in that project, and a number of readers have asked why we hadn't followed a 'direct sampling' approach to adapting a DVB-T dongle for MF and HF radio reception as an alternative to the up-converter approach we had used in the SiDRADIO.

It's true, a DVB-T dongle can be modified for MF and HF reception using direct sampling; but, compared with the use of a preselector and an up-converter there are shortcomings in this approach with regard to reception performance.

That said, the direct sampling approach is fine if you just want to use a spare DVB-T dongle for SDR reception of local AM radio signals. However for proper reception on the LF or shortwave bands the SiDRADIO project mentioned above is preferable.

Then I came across the Banggood low-cost (currently £16.50, free shipping) SDR kit reviewed in this article (Banggood Product ID: 1120249: www.bit.ly/2MDz7D3). It uses (you guessed it) the direct sampling approach for reception below 30MHz. What's more, they've worked out a way to do this in addition to the standard no-mods-to-the-dongle VHF and UHF reception, so that switching between the two bands is achieved entirely in software.

In short, they've taken advantage of the direct sampling approach to come up with a very neat little DVB-T-dongle-based SDR solution, in kit form, and at a surprisingly low price.

It does have a few tricky aspects in terms of kit assembly and also some limitations in terms of performance, but it would still make a very good introduction to Software-Defined Radio.

The assembled kit is claimed to tune from 100kHz to 1.7GHz, in two overlapping ranges: 100kHz to 30MHz using the direct sampling input and 25MHz to 1.7GHz using the regular dongle antenna input. It all runs off the 5V DC from a PC's USB port, which is also used for communications between the dongle and PC. In operation, it draws around 280mA.

The complete, assembled SDR is housed in a neat little metal case measuring only 83 × 50 × 20mm, finished in matte black enamel.

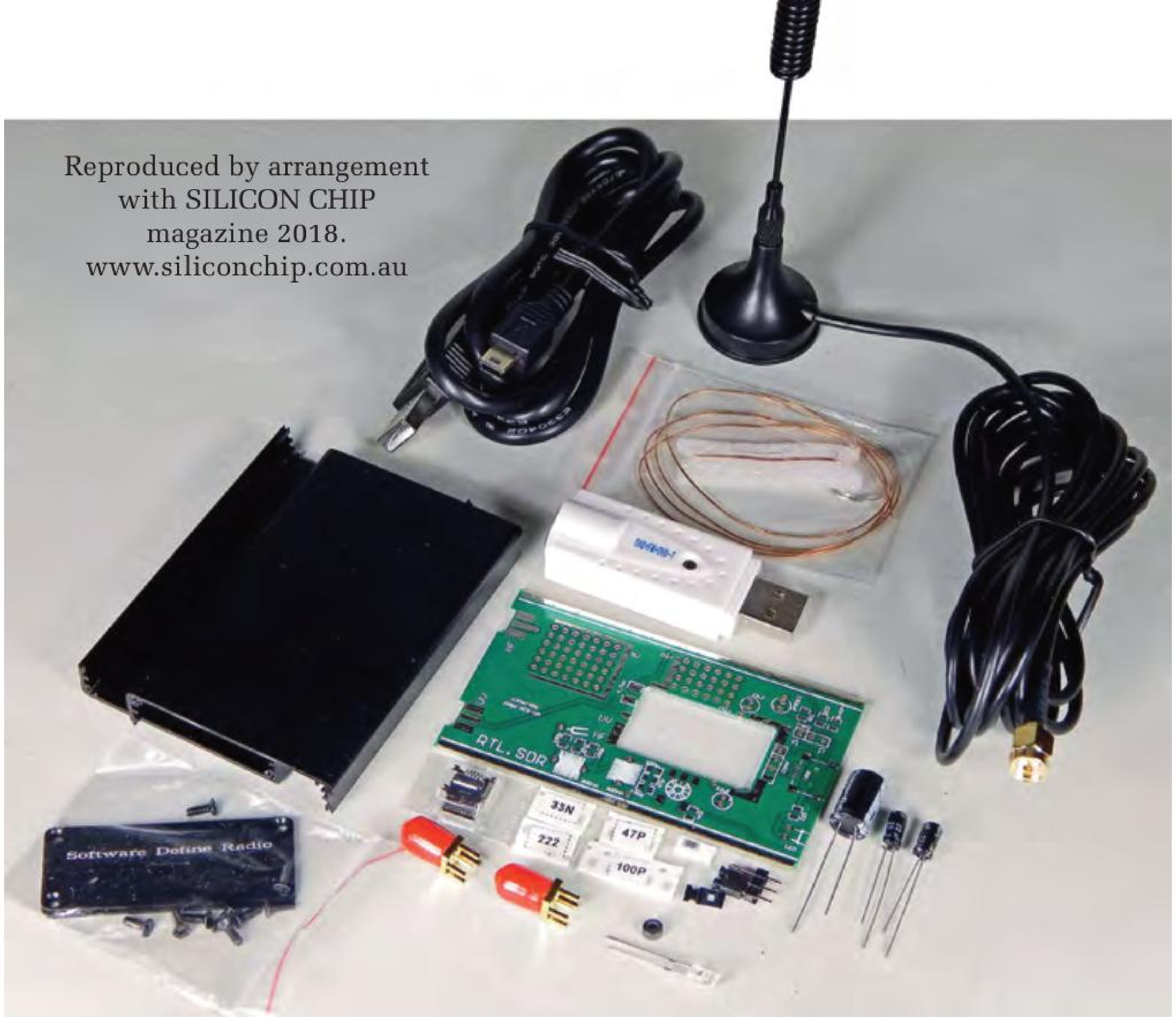
What you get in the kit

As shown in the photo, the kit comes with pretty well everything you'll need to build it: a very compact DVB-T dongle, a PCB for the rest of the circuitry, the parts for the metal case (including the M2 assembly screws), two edge-mounting SMA sockets for the RF input connectors, a mini-USB socket and all of the minor passive components.

This includes the SMD capacitors and resistors, three small electrolytic capacitors and two LEDs. There's also a tiny ferrite toroid (5mm outer diameter) for winding the coupling balun, plus a length of very fine (0.06mm outer diameter) enamelled copper wire to wind it. There's also a length of 0.5mm outer diameter enamelled copper wire to wind the two small low-pass filter coils.

You also get a 1m USB cable to hook up the finished SDR to your PC, plus a 250mm-long loaded whip antenna with a 2.9m cable fitted with an SMA plug for connecting it to either of the SDR input sockets.

You can download a seven-page PDF from the Banggood website which includes the kit assembly instructions. The text is a bit sketchy in places and doesn't explain some things particularly well, but there are quite a few photos which help clarify things.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The Banggood SDR kit comes with everything needed to build it. However, you may find an external and/or active antenna improves its performance.

The kit comes with one spare component for each of the SMD capacitors and resistors, in case one of any of these tiny parts is lost. There's also one additional M2 screw along with the eight needed to assemble the SDR case. Very helpful!

One thing you don't get, though, is the software needed to run the SDR on your PC. For this, you need to download an SDR application like SDR# (available from **www.airspy.com**).

If you haven't played with dongle-based SDR before it's also a good idea to go to the RTL-SDR website (**www.rtl-sdr.com**) and download their *Quick Start Guide* file, which explains a lot about installing SDR# and the drivers it needs in order to communicate with a dongle-based SDR. Plus, we have listed the series of steps required to install SDR# in a panel in this article.

A quick look at the circuit

Just before we discuss assembling the kit, take a look at the circuit diagram, Fig.1. This is much clearer and easier to follow than the one included in the instructions from Banggood.

The circuitry of the dongle itself is shown in simplified form inside the light-green filled rectangular area in the centre. As you can see, it uses two main ICs: a Rafael Micro R820T VHF-UHF tuner chip and the Realtek RTL2832U digital demodulator chip with its inbuilt USB interface. The latter is really the heart of the dongle and also that of the overall SDR.

Notice that by using a dongle with the R820T tuner chip ahead of the RTL2832U, Banggood's designers have made it easier to use the direct sampling approach. That's because the R820T has only one pair of differential outputs, rather than the two pairs used by other popular tuner chips like the Elonics E4000 or the Fitipower FC0013.

Since the outputs from the R820T only use the I+ and I– inputs of the RTL2832U, this leaves its Q+ and Q– inputs free for feeding in the LF-HF input signals for direct sampling.

The components and wiring outside the green rectangle in Fig.1 is the additional circuitry used in the Banggood SDR kit, to extend its frequency range downwards to 100kHz, and also to improve its performance and flexibility.

The circuitry at lower left is used for direct sampling of lower frequencies, and as you can see is fairly straightforward. The signals first pass through a two-stage low-pass filter comprising coils L1 and L2, plus their associated capacitors; then balun transformer T1 is used to change them into differential form to feed into the Q+ and Q– inputs of the RTL2832U.

Finally, note that the kit designers have also made provision for both of the SDR inputs to be provided with 5V DC 'phantom' power, by using the A setting of link header CON2 (at upper right). This makes it easy to use active antennas with the SDR, or to use a preselector with gain in the case of the direct sampling LF-HF input. It's a nice feature which doesn't seem to be explained in the assembly instructions.

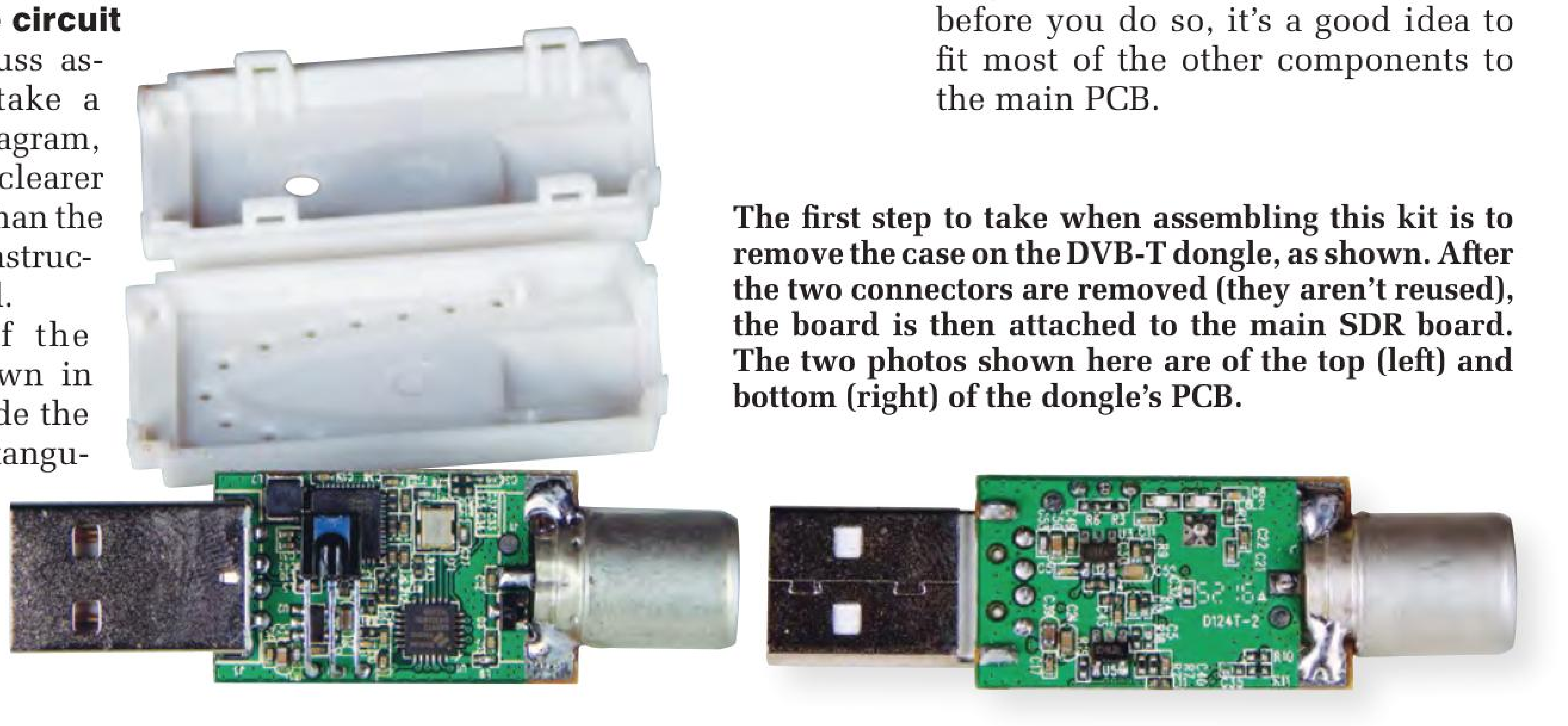
Assembling the kit

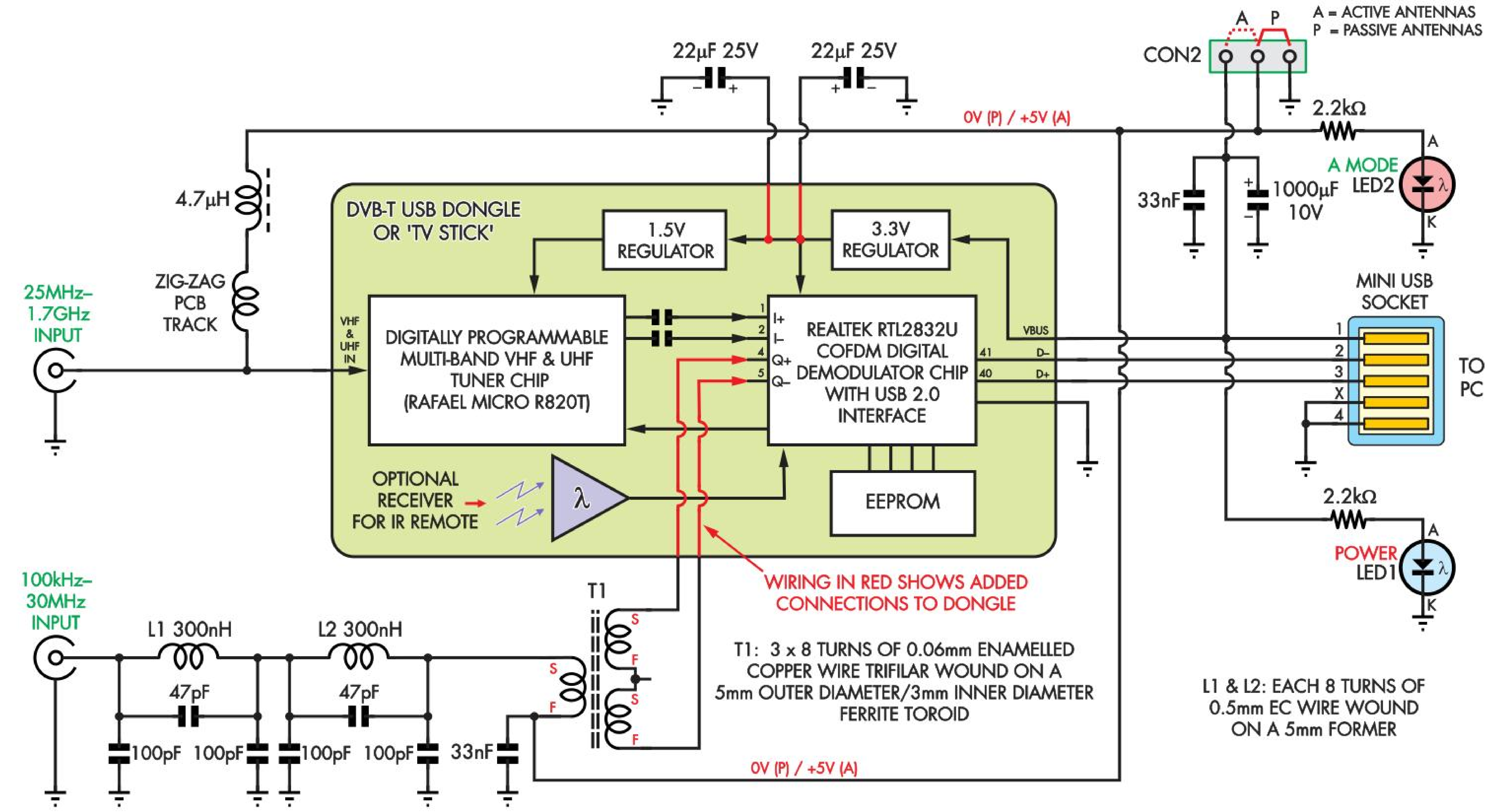
The first step in building the kit is to prise open the DVB-T dongle's plastic case to reveal the tiny PCB assembly; the PCB itself measures only 28 x 17mm and is shown below. The next steps are to remove the USB type A plug from one end of the PCB and the Belling-Lee RF socket from the other end.

These steps turn out to be a little tricky because you have to do them with a fairly high-powered soldering iron while at the same time being careful not to damage the many tiny SMD components already fitted to both sides of the PCB.

To make things easier for myself, I first used a jeweller's saw to cut off both connectors level with the ends of the PCB, leaving only their inner portions to be desoldered and removed.

Once the connectors have been removed and their holes in the PCB cleaned up, it is ready to be fitted inside the main SDR PCB, in the rectangular cut-out in the centre. But before you do so, it's a good idea to fit most of the other components to the main PCB.


The first step to take when assembling this kit is to remove the case on the DVB-T dongle, as shown. After the two connectors are removed (they aren't reused), the board is then attached to the main SDR board. The two photos shown here are of the top (left) and bottom (right) of the dongle's PCB.


22µF 25V
22µF 25V
A = ACTIVE ANTENNAS
P = PASSIVE ANTENNAS
CON2
A
P
0V (P) / +5V (A)
2.2kΩ
A MODE
LED2
33nF
1000µF
10V
4.7µH
ZIG-ZAG
PCB
TRACK
25MHz–
1.7GHz
INPUT
DVB-T USB DONGLE
OR 'TV STICK'
1.5V
REGULATOR
3.3V
REGULATOR
VHF & UHF IN
DIGITALLY PROGRAMMABLE
MULTI-BAND VHF & UHF
TUNER CHIP
(RAFAEL MICRO R820T)
REALTEK RTL2832U
COFDM DIGITAL
DEMODULATOR CHIP
WITH USB 2.0
INTERFACE
I+
I–
Q+
Q–
VBUS
D–
D+
MINI USB
SOCKET
TO
PC
OPTIONAL
RECEIVER
FOR IR REMOTE
EEPROM
2.2kΩ
POWER
LED1
WIRING IN RED SHOWS ADDED
CONNECTIONS TO DONGLE
100kHz–
30MHz
INPUT
L1 300nH
L2 300nH
47pF
47pF
100pF
100pF
100pF
100pF
33nF
T1
T1: 3 x 8 TURNS OF 0.06mm ENAMELLED
COPPER WIRE TRIFILAR WOUND ON A
5mm OUTER DIAMETER/3mm INNER DIAMETER
FERRITE TOROID
L1 & L2: EACH 8 TURNS OF
0.5mm EC WIRE WOUND
ON A 5mm FORMER
0V (P) / +5V (A)

BANGGOOD SOFTWARE-DEFINED RADIO

Fig.1: the heart of this software-defined radio (SDR) is the DVB-T dongle shown in the centre. It uses a multi-band tuner chip and the Realtek RTL2832U COFDM digital demodulator chip, which also provides the USB interface.

I added the SMD capacitors and resistors first, followed by the 4.7µH SMD inductor and SMD LED2. By the way, these are all 0805 parts (2.0 × 1.2mm), so you need a soldering iron with a fine and well-tinned tip.

After that, I fitted the two edge-mounted SMA sockets at the input end, followed by the SMD mini-USB connector at the output end. Then came a fiddly bit, I decided to solder the dongle PCB in place.

This needs to be done carefully; it's attached to the main PCB using short lengths of 1mm-diameter tinned copper wire or tiny pieces (3 × 4mm) of thin brass shim, soldered to each corner of the smaller PCB.

I found the easiest way to do this was to first solder these pieces to the ground copper on each corner of the top of the dongle PCB.

Then I could lower the assembly into the main board cutout, so the added pieces held it in place while I soldered the outer ends of each to the earth copper on the top of the main PCB. The kit designers have left these areas unmasked and pre-tinned.

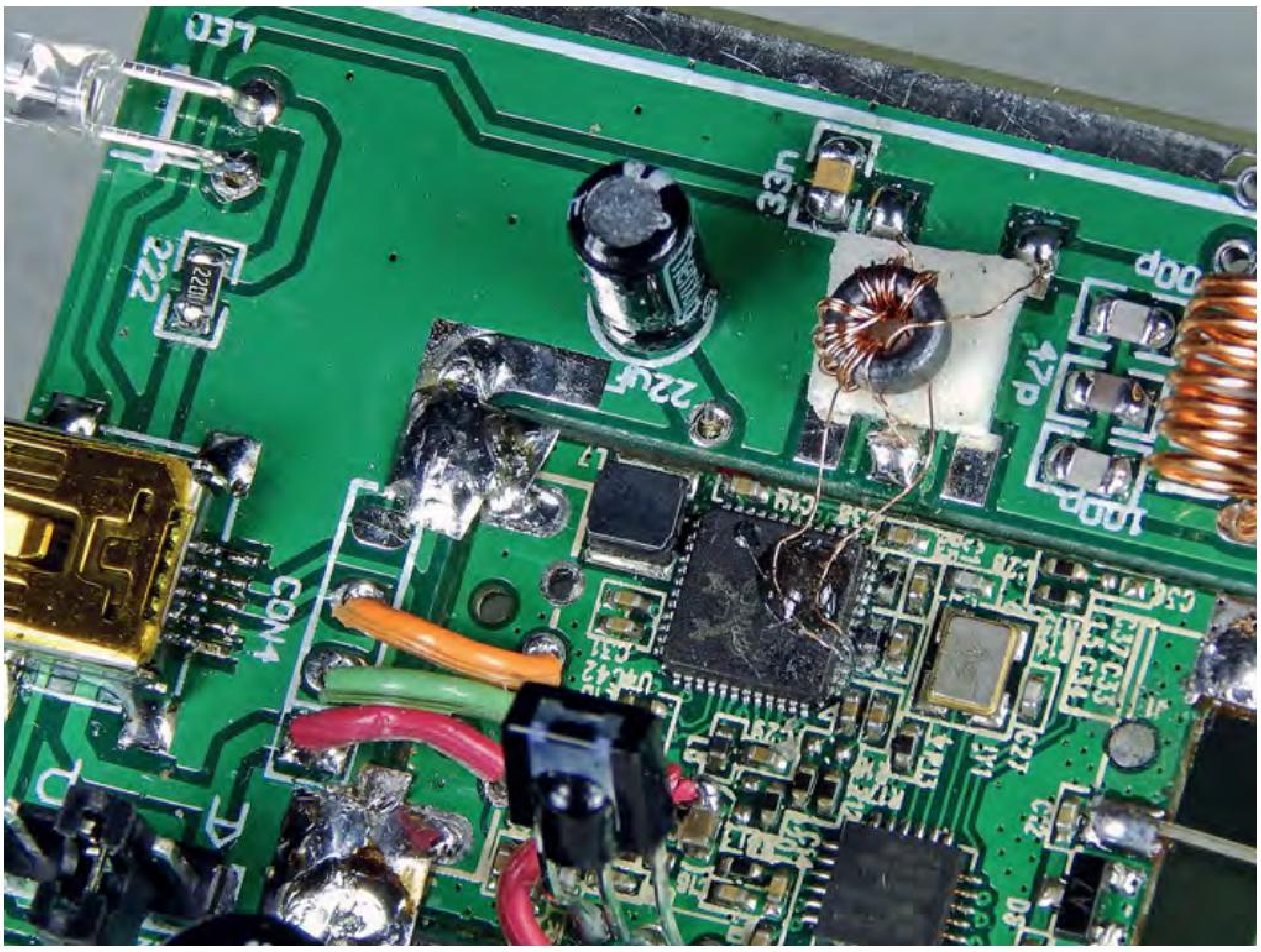
Next, came the really tricky steps associated with the tiny balun transformer (T1). First, I wound the tiny device, next came fitting it to the main PCB in the location shown, and finally the process of soldering the ends of its outer secondary wires to pins 4 (Q+) and 5 (Q–) of the RTL2832U demodulator chip on the dongle PCB.

Winding T1 isn't too hard, but since it's trifilar (three wires at once) using very fine wire (0.063mm diameter) on a very tiny (5mm OD, 3mm ID) toroidal ferrite core, it ain't easy either.

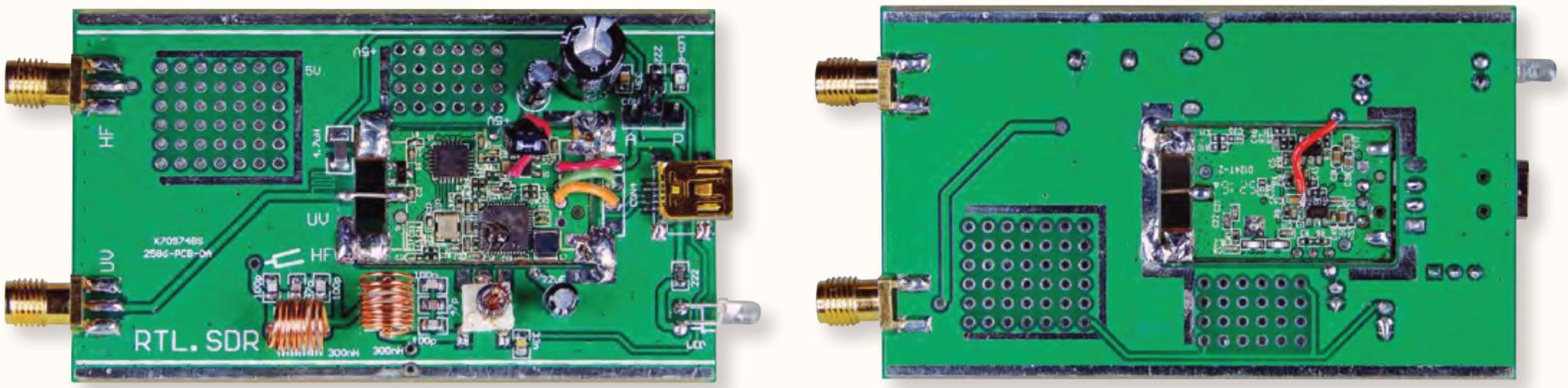
You first need to straighten the wire, then fold it into three, twist together and then thread the twisted wire trio through and around the miniature toroid eight times.

Next, cut them apart at each end and use a DMM to carefully identify the start and finish of each wire.

One of the wires becomes the transformer's primary, with its ends cut short and soldered to the pads between T1 and the board edge after you have attached T1 to the main PCB using a 5 × 6mm piece of double-sided adhesive tape.



A close-up of the assembled PCB showing the various connections required between it and the dongle. The most important assembly issue is the connection from toroidal transformer T1 to pins 4 and 5 of the RTL2832U micro.



The photos above show the top (left) and bottom (right) of the completed SDR board. There are a reasonable number of through-hole and SMD components that need to be soldered to the board, along with securing the dongle PCB in the cut-out. It's best to solder many of the smaller components to the board before attaching the dongle PCB as there isn't a lot of space to work with.

The start of one of the remaining wires is then twisted together with the finish of the other wire, and after cutting them short, they are then soldered to the centre pad between T1 and the dongle PCB.

The really tricky step is soldering the two remaining wire ends to pins 4 and 5 of the RTL2832U chip.

This is because the wire is extremely fine; the pins of the chip are spaced less than 0.4mm apart and there are tiny SMD components mounted on the top of the dongle PCB only about 1mm away from the body of the RTL2832, very close to pins 4 and 5. See the close-up photo of the finished job opposite left.

Frankly, I found soldering these wires to the chip pins very difficult, even using a binocular microscope and soldering iron with a very slim tip. I ended up having to use a drop of epoxy cement (Araldite) to hold the ends of the wires in position over pins 4 and 5.

Then, when the cement had cured, I was finally able to solder them to the pins without any solder bridges.

Once these steps had been done (phew!), assembling the rest of the kit was fairly straightforward. Completing the board assembly was mainly a matter of fitting the three small RB electrolytic caps plus the blue power LED and six additional wires making the connections between the two PCBs.

Five of these wires go on the top, with one of them being a short length of 0.8mm-diameter tinned copper wire connecting the input of the dongle PCB to the track on the main PCB coming from the VHF-UHF input connector (which is labelled 'UV', for some reason).

Three of the others are 7mm lengths of insulated hookup wire, which are used to make the power and USB connections at the other end of the dongle PCB.

The remaining wire is another 7mm length of insulated wire, used to connect one of the 22µF electrolytics (near the 1000µF electrolytic) to the output pin of 3.3V regulator U2, at the end nearest the RTL2832U.

The final wire goes under the PCB assembly, being a 14mm length of insulated wire used to connect the other 22µF capacitor on the main board in parallel with the SMD capacitor (C52) on the dongle PCB (see photo at upper right).

The very last components to fit on the main PCB are the two hand-wound low pass filter coils, L1 and L2. These are each wound from the 0.5mm enamelled copper wire, with eight turns wound on a 5mm diameter former like the shank of a 5mm drill bit. Then the wire ends are bent out radially and tinned, to allow them to be soldered to the pads provided to the left of T1 (see photo at left above).

Once these final components and wires have been fitted, the SDR board assembly is essentially complete and ready to be fitted into the lower part of the case.

This is done by sliding it into one of the channels in the sides until the SMA input sockets are protruding out at the far end. Then you attach that end plate, with the sockets passing through the matching holes.

After this, the front plate can be secured to the lower half of the case using two of the M2 screws.

The rear plate is fitted in the same way, after bending the leads of power LED1 so its body lines up with the matching 3mm hole. The mini USB socket will also protrude slightly through its matching hole.

All that remains is to attach the top half of the case, which simply involves lowering it into place (with the correct orientation, since the two halves have complementary ridges and slots) and then fitting a pair of M2 screws at each end.

Trying it out

I installed SDR# and its drivers (using Zadig, which comes with the SDR# package) on a couple of different Intel machines running Windows 7, 64-bit.

I did strike a bit of trouble initially because I had downloaded and installed the 64-bit version of SDR# and it didn't seem to be able to find the SDR device and its driver on either machine. Happily, this problem was solved by downloading and installing the 32-bit version.

Once I had SDR# up and running, I ran some tests on the 25MHz-1.7GHz tuning range, to verify the dongle's performance. The results were promising.

For example, a 5µV NFM (narrow-band FM) signal could be received clearly at various frequencies from 30.1MHz to 1.5GHz, with the peak carrier amplitudes and SNR (signal-to-noise ratio) figures as shown in Table 1.

Then I ran some similar tests on the direct sampling 100kHz-30MHz tuning range, this time using a 224µV AM signal with 30% modulation. The results are shown in Table 2.

These are still quite respectable, although the sensitivity on this range is understandably somewhat lower than that on the 25MHz-1.7GHz range because of the lack of front-end gain. There were rather more spurious 'birdies' too, because of the lack of any front-end tuning or preselection.

Note that I went beyond the nominal upper-frequency limit of 30MHz, just to see what the effect of the SDR's input low-pass filter might be. As you can see, the performance is still quite respectable up to 36MHz, so the filter doesn't seem to be too savage.

Since the performance with a signal level of 224µV was so promising, I decided to do a couple more tests at 15.02MHz (roughly in the centre of the tuning range), one with a signal level of 22.4µV, and the other with a signal level of 12.6µV. The results were still quite respectable, as shown in Table 3.

Installing SDR# and the required drivers on your PC

Please note that you may need to install the latest Microsoft .NET framework before you can install SDR# (SDR# since 2015 has required .NET 4.6 minimum to run). Having said that, most modern Windows machines (ie, Windows 7/8/10) should already have the .NET framework installed.

Also, the latest versions of SDR# will not run on Windows XP. Version XP is no longer supported and its users should upgrade to a newer version to avoid security problems. Similarly, while it will likely run on Vista, the operating system is no longer supported.

The other package that you may need on your system is the Visual C++ Runtime. The download locations for both packages are listed in the steps below.

The steps to install SDR# on a Windows PC are as follows (based on the *RTL-SDR quick start guide*):

1. Install the Microsoft .NET 4.6 redistributable, available from **www.microsoft.com** at: **http://bit.ly/2x1BdDh** (this is not required if it's already on your PC, which should typically be the case for Windows 10 users).
2. Install the Microsoft Visual C++ Runtime redistributable, available from **www.microsoft.com** at: **http://bit.ly/2oO6pRA** (again, this is not necessary if you already have it; the installer should tell you if you are not sure).
3. Click on the downloads button at the top of **www.airspy.com** and download the x86 version of **sdrsharp.zip** (next to the heading titled 'SDR Software Package').
4. Unzip **sdrsharp.zip** – but don't run anything yet.
5. Double click **install-rtlsdr.bat** within the extracted files. This should download the files **rtlsdr.dll** and **zadig.exe** into the same directory (you may need to run this batch file as an administrator).
6. Plug in the dongle and wait for Windows to attempt to install the drivers (it will likely fail).
7. Right-click **zadig.exe** – select 'Run as administrator'.
8. Make sure 'List All Devices' is checked in the Options menu.
9. Makes sure either 'Bulk-In, Interface (Interface)', 'RTL2832UHIDIR' or 'RTL2832U' is selected in the drop-down list.
10. Ensure that WinUSB is selected in the box to the right of the green arrow.
11. Click the Replace Driver button. You may get a warning that the publisher cannot be verified; if so, select 'Install this driver software anyway'. Note that you may need to run **zadig.exe** again if you move the dongle to another USB port.
12. Open **SDRSharp.exe**. Note that the first time you do this, you may get a message indicating that Windows has protected your PC. This is a false alarm, so click on 'more info' and then 'run anyway'.
13. Set the drop-down box in the 'Source' tab at upper left to 'RTL-SDR (USB)'.
14. Press the Play button.
15. Press the Configure button (looks like a gear) up the top, next to the Play button. By default, the RF gain is set at zero, so adjust it upwards until you start seeing the expected RF signals being picked up in the SDR display.

That's it, your SDR# software is ready to go.

The bottom line

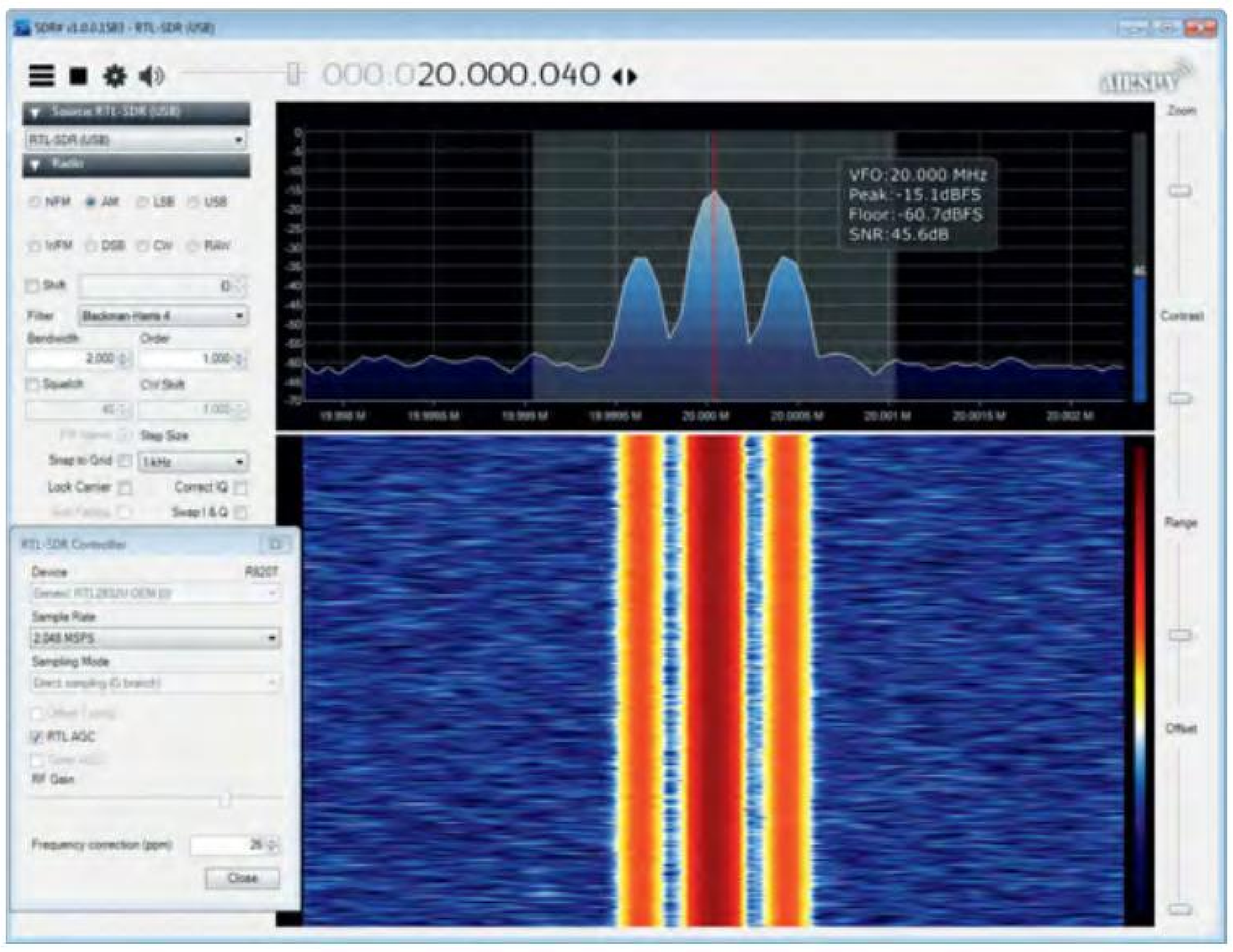
So here are the good points about Banggood's dongle-based SDR kit:

- Its very low price
- Quite respectable performance over most of the claimed tuning range, from about 100kHz to over 1.5GHz
- Quality and completeness of the kit, right down to those extra SMD components and the additional M2 case assembly screws

On the other hand, here are the not-so-good points:

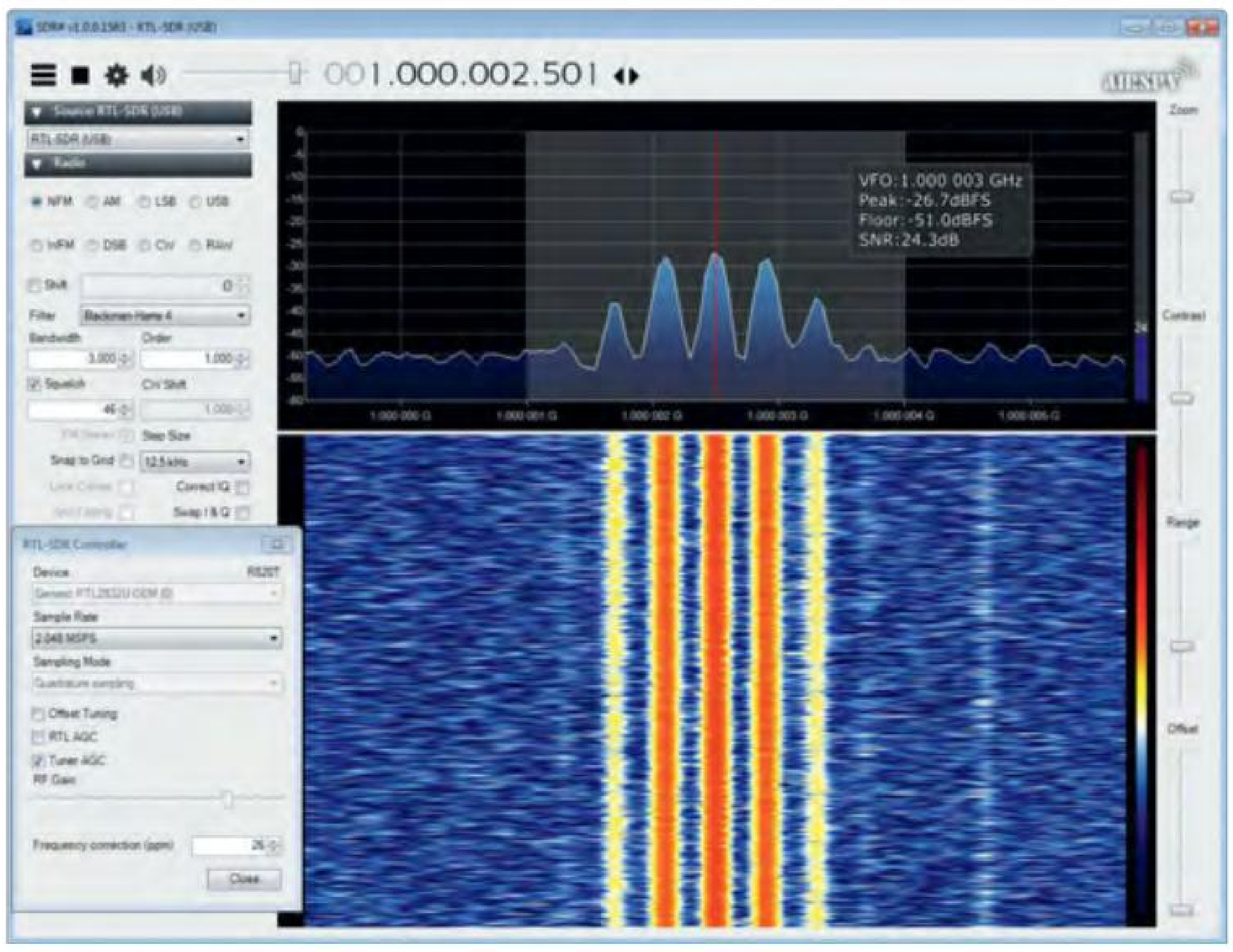
- There are some aspects of kit assembly that present quite a challenge, like winding the balun transformer T1 and then soldering the fine wires from its secondary to pins 4 and 5 of the dongle's RTL2832U chip
- The sensitivity and selectivity of the finished SDR does leave a bit to be desired, especially on the LF/HF direct sampling range. For serious listening, you'd be advised to use either a very long external antenna with a good earth and/or (preferably) an active antenna to provide both some gain and some preselection.

Actually, I can verify that the kit's performance does benefit from the use of an active indoor loop antenna because


000.020.000.040

VFO:20.000 MHz
Peak:-15.1dBFS
Floor:-60.7dBFS
SNR:45.6dB

224µV 20MHz AM test waveform in SDR#.


001.000.002.501

VFO:1.000 003 GHz
Peak:-26.7dBFS
Floor:-51.0dBFS
SNR:24.3dB

5µV 1GHz NFM signal in SDR#.

BANGGOOD SDR PERFORMANCE ON THE VHF-UHF RANGE (5µV NFM signal)

Frequency (MHz)	Carrier Peak (dBFS)	Noise Floor (dBFS)	Signal/Noise Ratio (dB)
30.1	-23.2	-50.4	27.2
110.1	-18.1	-48.3	30.3
150.0	-4.4	-42.7	38.2
500.0	-15.6	-46.4	30.5
800.0	-22.0	-47.1	25.1
1000.0	-26.7	-51.0	24.3
1200.0	-31.1	-48.7	17.7
1400.0	-34.6	-55.7	21.1
1500.0	-36.4	-53.0	16.6

TABLE 1 NOTE: dBFS = dB relative to full scale

BANGGOOD SDR PERFORMANCE ON THE LF-HF RANGE (224µV 30% AM signal)

Frequency (MHz)	Carrier Peak (dBFS)	Noise Floor (dBFS)	Signal/Noise Ratio (dB)
0.1449	-30.3	-61.2	30.9
0.4499	-22.3	-61.9	39.6
1.800	-17.5	-61.3	43.8
5.100	-17.4	-60.4	43.0
10.200	-16.7	-60.4	43.7
15.020	-14.6	-61.7	47.1
20.000	-15.1	-60.7	45.6
25.000	-17.3	-61.5	44.3
30.000	-15.3	-62.3	47.0
34.500	-27.1	-59.9	32.8
35.500	-31.8	-59.7	27.9
36.000	-34.6	-60.7	26.1

TABLE 2 NOTE: dBFS = dB relative to full scale

BANGGOOD SDR PERFORMANCE ON THE LF-HF RANGE (15.02MHz 30% AM signal)

Signal Level (µV)	Carrier Peak (dBFS)	Noise Floor (dBFS)	Signal/Noise Ratio (dB)
22.4	-35.3	-61.3	26.0
12.6	-40.2	-61.4	21.2

TABLE 3 NOTE: dBFS = dB relative to full scale

100KHz - 30MHz
25MHz - 1.7GHz

I tried it out with the low-cost Sino-Radios TG34 antenna.

It worked quite well, and when I looked on eBay to see if it was still available, I found it at: **www.ebay.com.au/itm/130392486862** (this will ship to the UK, total price including deilivery of around £17).

Banggood (item ID 1120579) has a very similar unit called the Degen DE31MS, which you'll find at: **www.bit.ly/2Czt0ey** (around £14 to the UK).

One final suggestion: although the extruded metal case of the Banggood kit does provide some shielding for the SDR circuitry, this could be improved by adding some short wires between the PCB earth copper and solder lugs attached firmly to the inside of the upper and lower parts of the case.

This ensures that the case is reliably connected to PCB earth, and so is able to provide full shielding, resulting in significantly lower interference.

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Dynamo bicycle LED lighting system

by Julian Edgar

This clever system effectively boosts the output of a dynamo at low speeds and adds a supercapacitor pack so the lights stay on when you're stopped.

LED lighting has revolutionised bicycle lights. No longer do you have a feeble yellow glow-worm at the front and a tiny dull red light at the rear. Nope – you can have battery-powered brilliance, both front and back! That's a good thing – but there's a problem – and that was in the term 'battery-powered'. Even if your batteries are USB rechargeable, then sure as night follows day, when you want to ride your bike, you'll find the batteries flat. Or, even worse, on a long ride you find you've pushed the limits just a little too far and again you're left without a front or rear light.

The solution is to use dynamo lights, where you provide the energy, and the lights are always available and working. The trouble is, unless you're prepared to pay a lot of money, dynamo lighting hasn't kept pace with battery LED lights. But the project covered here changes all of that.

Using just an off-the-shelf module and a few extra components, you can have dynamo lighting that attains full brilliance at any speed above a walking pace, uses almost no energy from your legs, and shines brightly enough to both make you visible and show you the way. If you wish, you can even configure the system to charge a phone! And, if you add a low-cost capacitor pack, you can also have dynamo lights that stay on for a while when you're stationary.

Building blocks

So what approach is taken? The AC output of the dynamo is rectified and

Table 1: LED lighting system voltage options

System voltage	Application
3V	LED lights normally powered by two 1.5V cells
5V	LED lights designed for USB use, or charge a phone
6V	LED or filament lights designed for dynamo use
12V	12V LEDs: also allows the use of 12V accessories; eg, phone charger

Hub versus bottle bike dynamos

This article uses a Shutter Precision SV-9 hub dynamo as the basis of the system. A hub dynamo – as the name suggests – replaces the wheel hub, so it needs to be incorporated into the bicycle wheel when the wheel is built. Compared with 'bottle dynamos' that have a small diameter knurled wheel that bears against the side of the tyre, hub dynamos are much more efficient – they have vastly lower frictional losses. However, hub dynamos are also more expensive. The project covered here should also work with a bottle dynamo.

An elegant French 1953 EDELKO SELF 'bottle' dynamo, rated at 3W
Photo courtesy of Nola Wilken, https://restoringvintagebicycles.com

Shutter Precision SV-9 hub dynamo

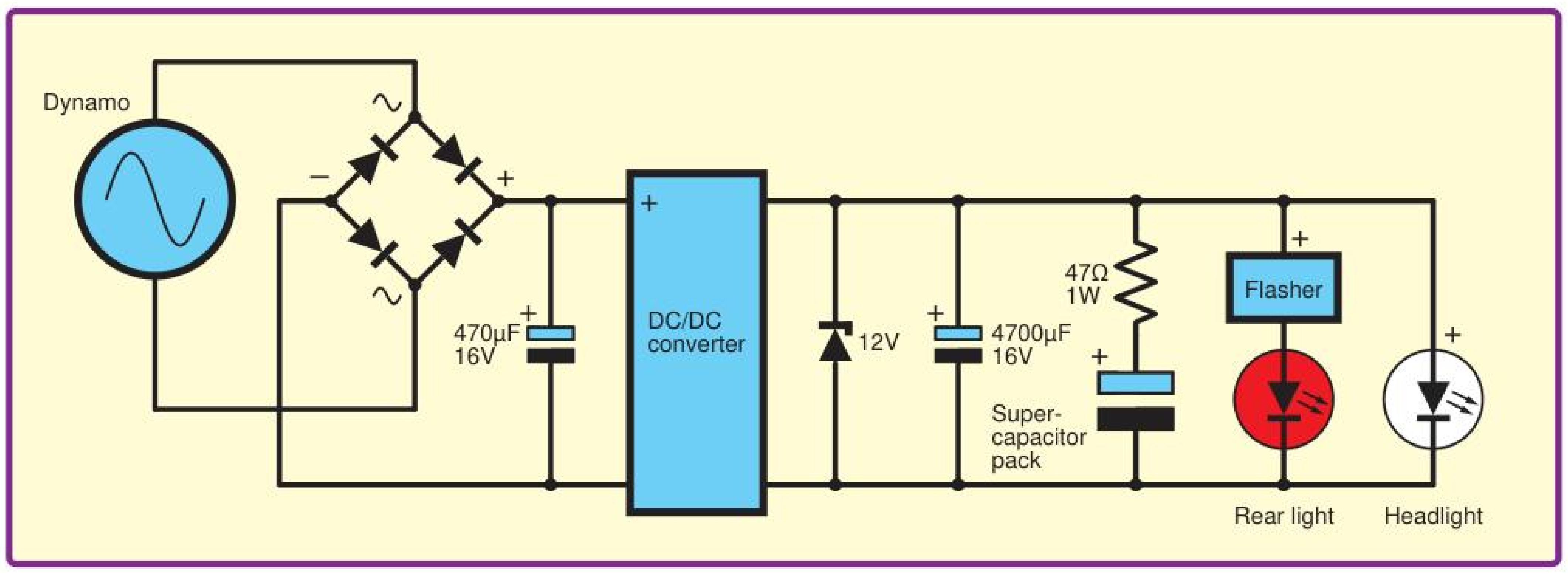


Fig.1. Here we have a schematic of the main system components. The dynamo's output is rectified and smoothed and then fed to the DC/DC buck/boost converter, set to 12V. On the output of the converter, a 12V zener diode clips the spike that otherwise occurs when the converter first starts to operate. The 4700µF capacitor reduces headlight flicker caused by the alternating load of the rear flasher. The supercapacitor pack feeds through a 47Ω resistor that limits the capacitor pack's charge rate and so doesn't overly impact the brightness of the lights. The rear light is fed through a flasher module, and the headlight is powered directly from the 12V feed – both front and rear LEDs are designed for 12V use. The system gives bright lights from a walking pace, and keeps the lights running for a period when the bike has stopped moving.

filtered, producing a DC output. This is fed to a DC/DC buck/boost converter that outputs a constant voltage. Using the on-board potentiometer, this voltage can be set to suit your system's requirements – we used 12V. Table 1 shows some of the voltages you could select for use in different applications.

The use of the DC/DC converter transforms the effectiveness of the dynamo. First, the DC/DC converter will work down to 3V, and the hub dynamo will produce this at just a walking pace. Second, the DC/DC converter better matches the load to the dynamo. Bike dynamos – of all sorts – are rated at 3W and 6V. However, that power is normally available only at higher speeds. With the DC/DC converter, you can achieve 3W output at very slow speeds. Therefore, unlike almost any other dynamo-based bike lighting system, with this system, you have full light brightness whenever you are moving. For anyone used to the idea that bike lights get brighter as you go faster, it's uncanny just starting off and seeing the lights suddenly come on at full brilliance.

In addition to selecting the system voltage to suit your requirements, you can also specify the type of lights. For example, in some jurisdictions, flashing lights (either front or rear) are illegal. In that case, you can use lights that are on continuously. And sometimes, even when a flashing light is legal, you might want a steady light – eg for the headlight in a dark area. When you design your own system, you can do whatever best suits your application.

Getting the supply

To run flashers or DC/DC converters you'll need to be working with DC – but bike dynamos produce AC. While I have read of some very tricky approaches to bicycle dynamo rectification, I went with a simple bridge rectifier and a 470µF electrolytic smoothing capacitor – see Fig.1. I over-rated the rectifier (using a 10A one) to avoid the need for any heatsinking. The rectified AC then feeds the input to the DC/DC converter, the module covered in this month's *Electronic Building Blocks* article on p.68. The module is available from **www.banggood.com** and costs just around £2 delivered – product ID 1087346. The tiny buck-boost module has a maximum input current of 1A, so is fine in this application.

However, in testing I found that the DC/DC converter module takes a few moments to start regulating – and during this time, full dynamo voltage went to the load. To clip this, I used a zener diode across the module's output. For the 12V system output I selected, a 1N5349 5W diode was used without a current-limiting resistor – the overshoot is very short in duration. Note that you should specify the diode voltage to match (or actually be a fraction higher) than the voltage you've chosen for the system.

A 4700µF capacitor is used on the output to smooth the headlight flashing that otherwise occurs as the tail-light flashes and the system load varies.

The next step is to just connect the output of the DC/DC converter to your chosen LED lighting. But what LEDs should you use? I spent some time experimenting to come up with the brightest, cheapest and lowest-power consumption system that I could find that worked well.

LED Lights

The first point to remember when specifying appropriate LEDs is that a normal bike dynamo outputs only 3W. So if you're thinking about a 5W

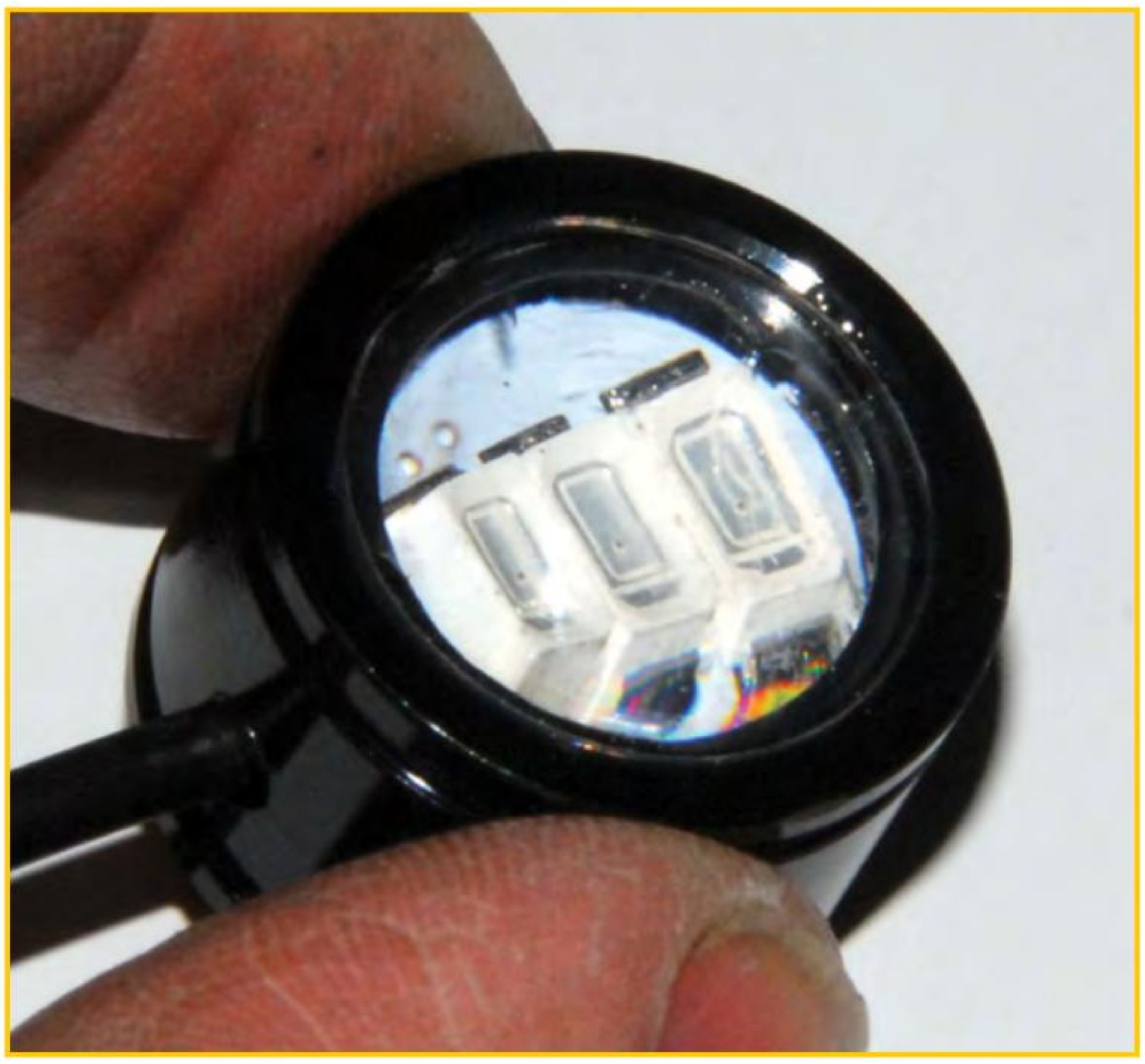


Fig.2. The tail-light uses a red LED assembly and flasher module. Average power is just 0.25W yet it is visible from over 100m. I opted to use the supplied housing and bracket for mounting the light on my bike.

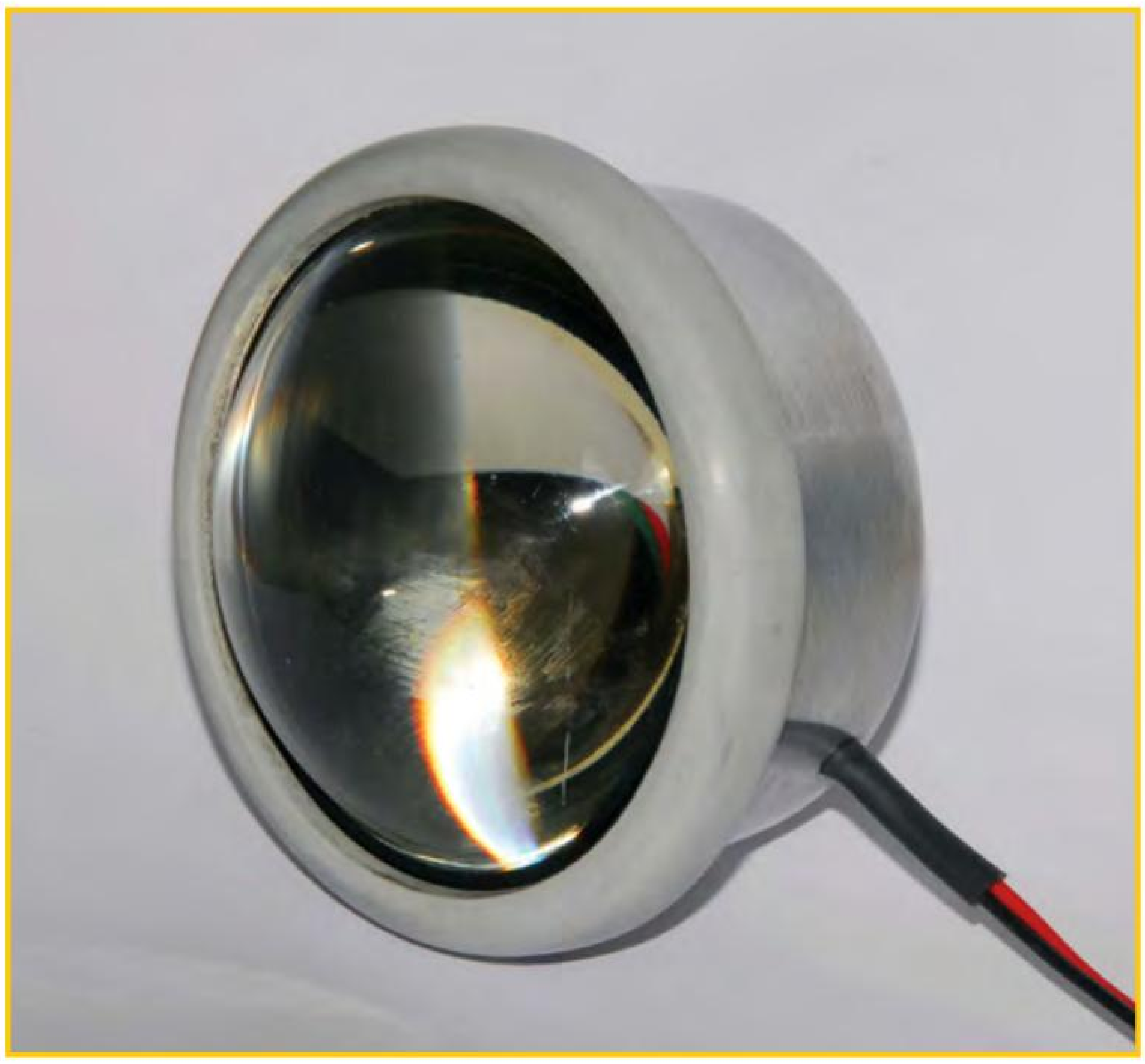
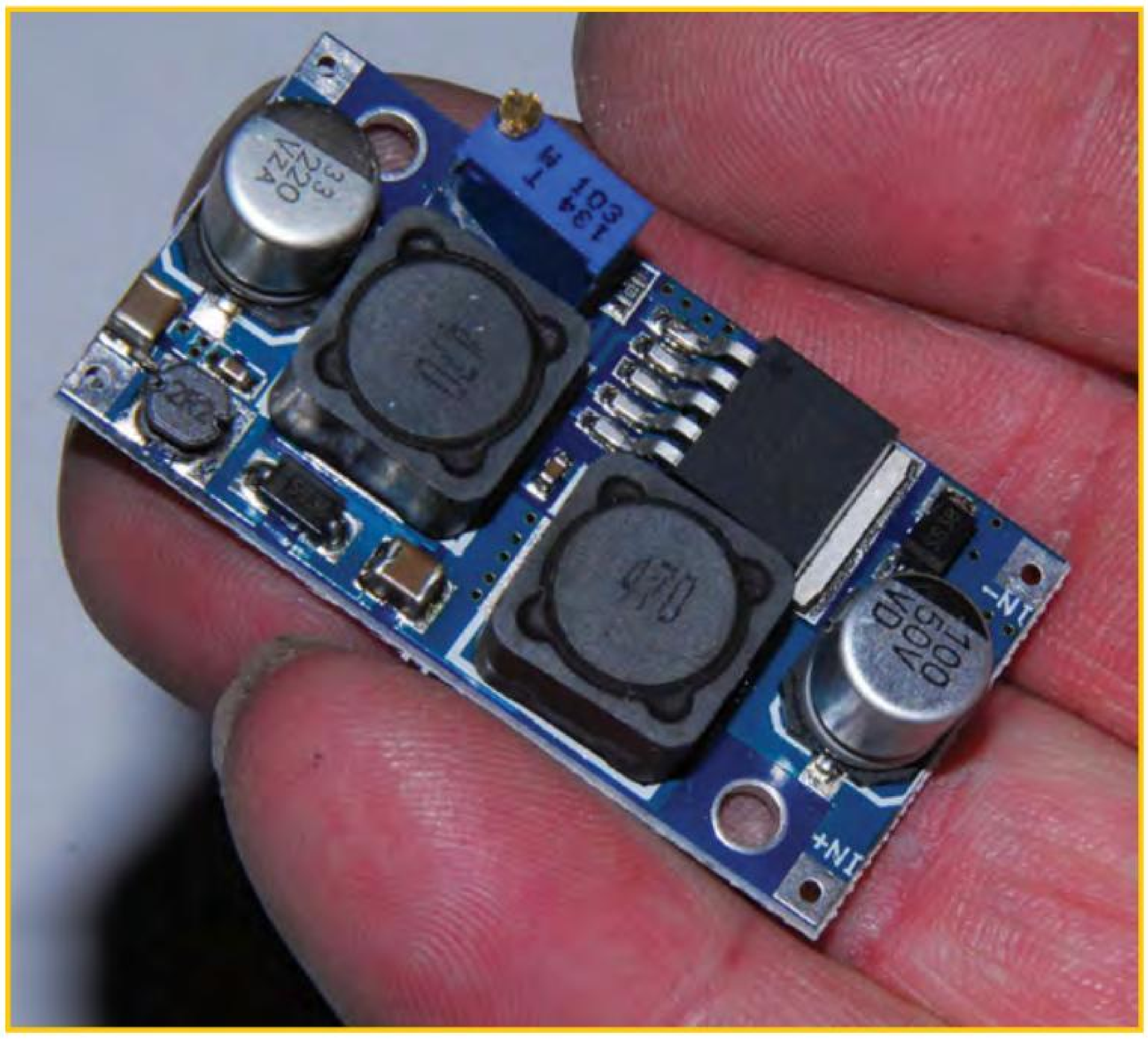


FIg.3. The LED headlight was made from a 64mm convex glass lens, a shortened aluminium drinking cup and an LED light. The plastic rim is a cut-down plumbing cap. The light gives a broad, even beam and has a power demand of only 0.8W.



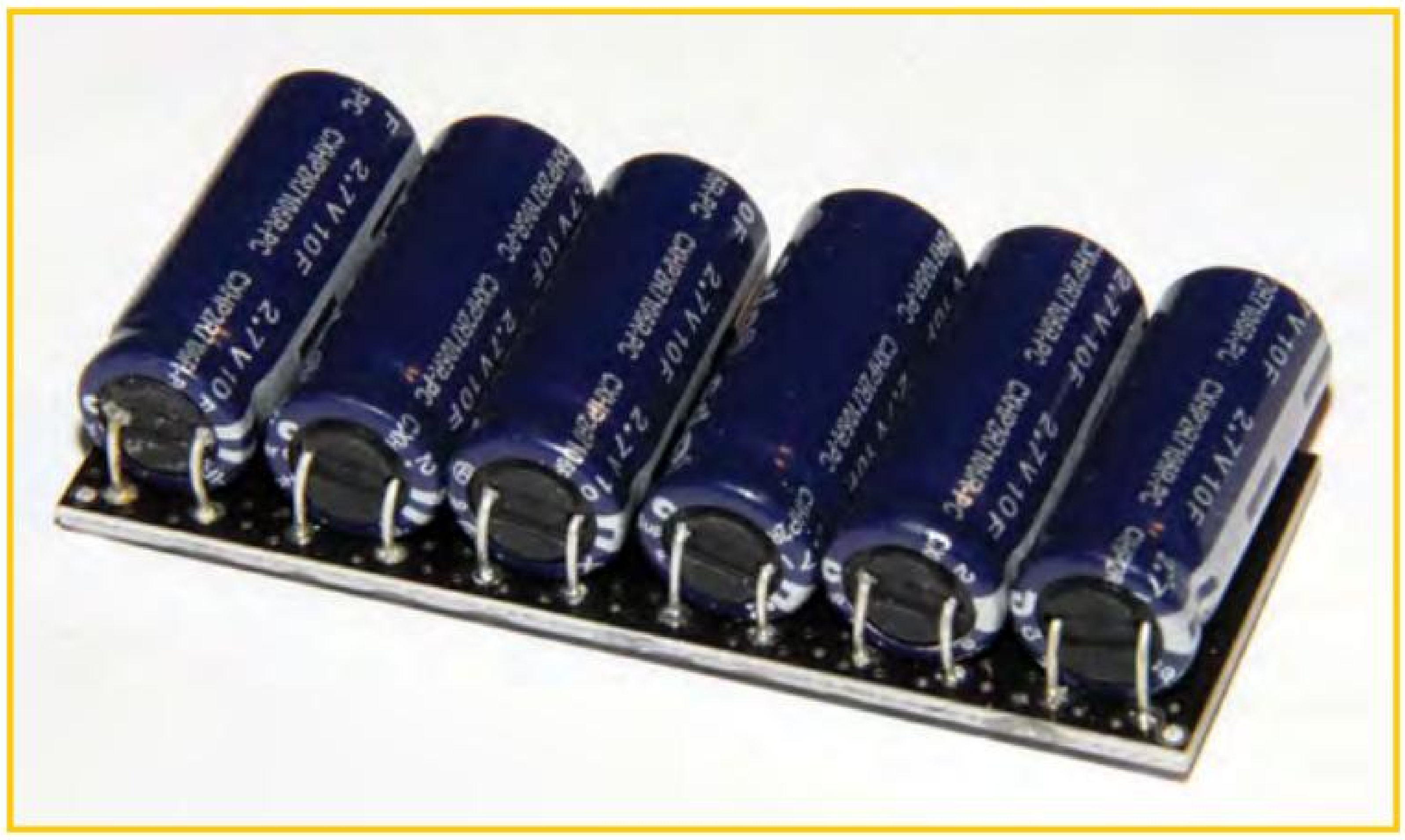


Fig.5 (above) This supercapacitor pack is used to maintain light output, even when the bike is stationary.

Fig.4 (left) This buck/boost module maintains a constant output voltage, even when working with the variable speed bicycle dynamo. The AC from the dynamo is rectified and filtered before being fed to this module.

headlight and a 1W tail-light – stop! You don't have enough power! You therefore need to be careful to choose lower-power LEDs that are really efficient – both in lumens produced per watt, and in their optics. (And of course, high-efficiency lighting also helps reduce pedal effort.)

For the LED light source, I chose to use another product sold by Banggood – 'Pair 12V Motorcycle Mirror Mount Eagle Eye LED Flash Strobe Backup DRL Lights Lamp' – product ID 1127241, costing just over £3 delivered. They're available in multiple colours, including red and white, as shown in Fig.2.

As purchased, these lights comprise two LED lights (each containing three individual LEDs and fronted with a lens) wired to a tiny in-line flasher module covered in heat-shrink. Connect the system to 12V and you'll find the system's average power is only 0.5W – very low for the extreme brightness and high-speed flashing.

These LEDs are also very efficient, and so are good for non-flashing purposes. Simply unsolder the leads (or cut them) and you have standalone 12V LEDs that can be used as steady lights. I chose to use one light taken from a white flashing pair as the steady headlight (ie, it was used without its flasher module) and one from a red pair as the rear light, this time used with its flasher module. Run in this way, the headlight has a power of about 0.8W and the rear light an average power of just 0.25W. Both were run off the nominally 12V output supply of the DC/DC converter.

The rear light was able to be mounted using the provided bracket, but the headlight took a bit of development. When developing a custom headlight, best results come from using an LED (equipped with a lens or collimator) and then a second lens, spaced away from the LED assembly, that focuses the beam. To build the headlight – shown in Fig.3 – I mounted the LED light in a cut-down aluminium drinking cup, and used a 64mm convex lens taken from a 'projector' style car headlight. This gave a very even, broad beam with a reach of about 12m and a width of about 5m.

(When devising a headlight like this, just use a bench power supply and a darkened room and trial lots of different optical approaches. In the past, I have used a 75mm magnifying glass as the focusing lens, with the lens placed across the mouth of a stainless-steel cup and the LED, with internal reflecting collimator, mounted in the base of the cup. Banggood sell glass convex lenses with mounts – search under 'LED collimator'. By altering the optics, you can have anything from a narrow, bright beam to a wider, less bright spread. It's really a case of experimenting and seeing what works best for your riding application.)

Of course, if you don't want to make your own headlight, you can just select an off-the-shelf 1W LED bike headlight – eg, one that works from two AA cells. Pick a tail-light that also operates from 3V and then run a system voltage of 3V.

So you now have a high-efficiency hub dynamo lighting system that will make you visible from the rear from a large distance, and light the way that you are going. But what about when you're stopped? Then the lights will go out. The way to fix that is to add a supercapacitor pack.

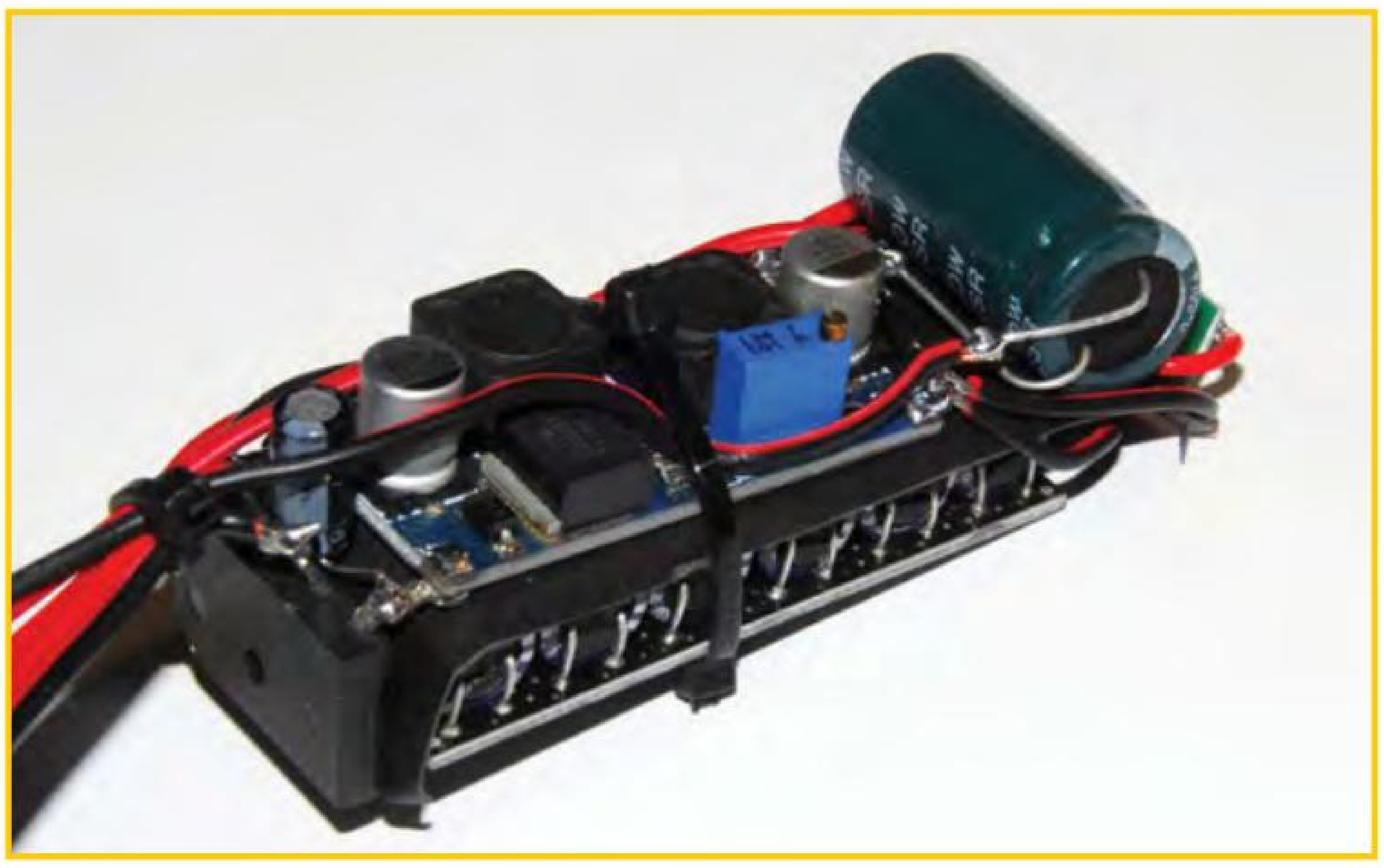


FIg.6. The completed electronics – note the rectifier and filter capacitor are at left. The top board is the DC/DC converter, with the supercapacitor board beneath. At right, just visible is the zener diode that clips any excessive output before the DC/DC converter starts to function, and the capacitor that smooths light flicker before the supercapacitor pack is charged.

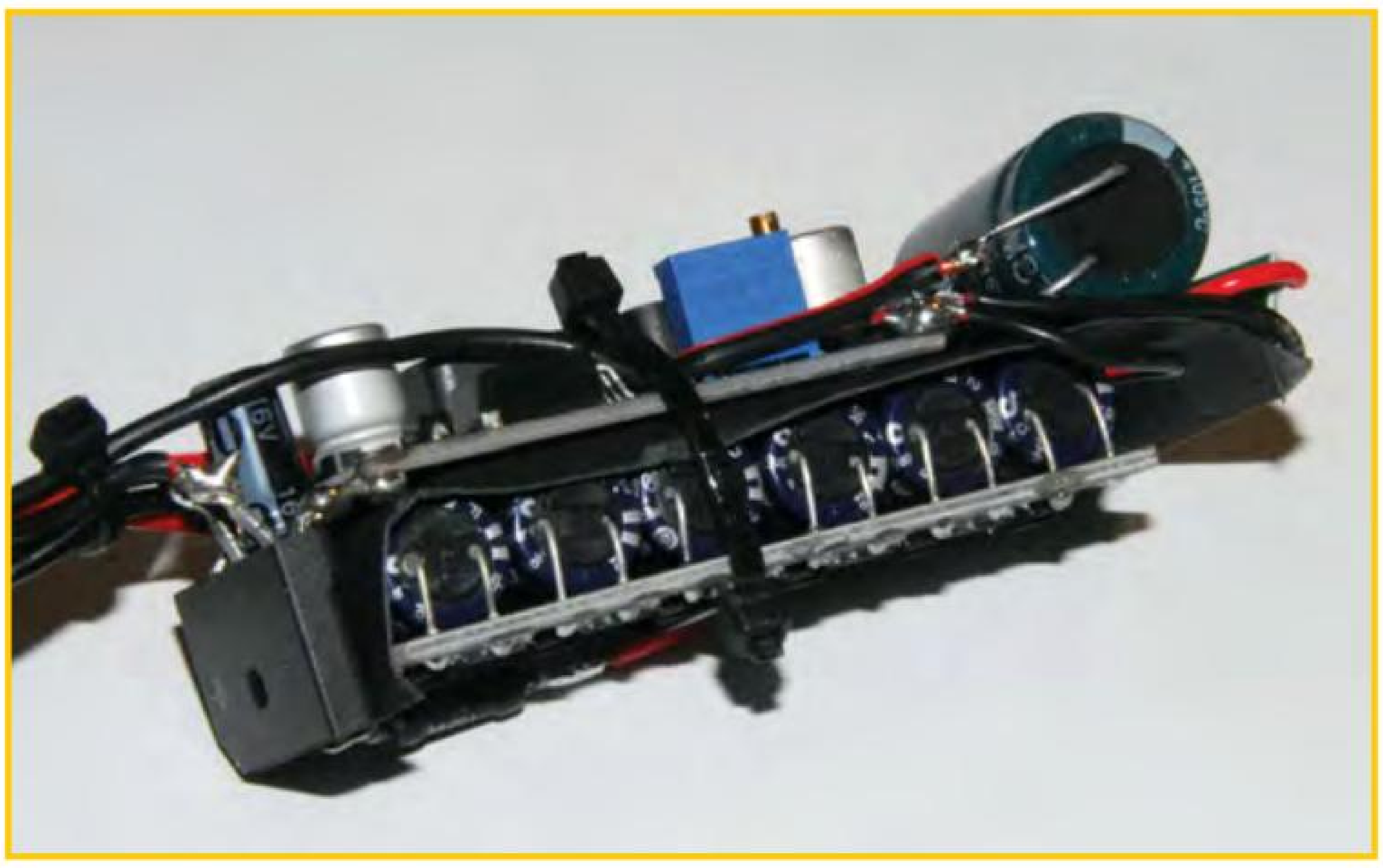


Fig.7. This side view of the electronics sandwich shows a sheet of insulating material was placed between the two boards. Just visible at bottom left is the resistor through which the supercapacitor pack is fed.

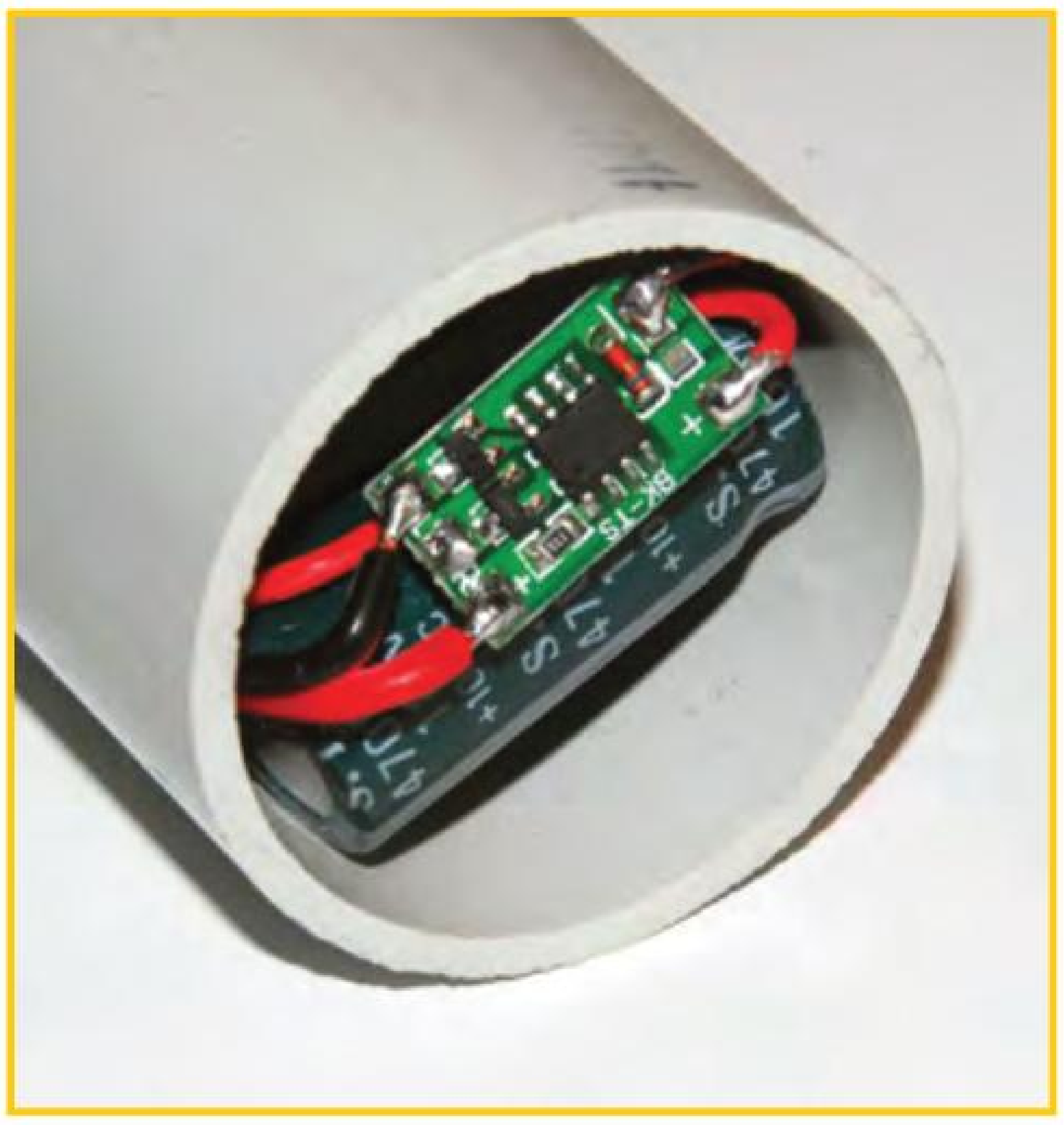


Fig.8. The assembly (just!) slides into a short length of 44mm-diameter plastic pipe and is sealed at each end with plastic end caps. Visible here is the flasher module, as supplied with the flashing LED used for the tail-light. We chose to subsequently pot the electronics in epoxy to make them vibration- and water-proof.

Super cap pack

The capacitor pack (Fig.5) is available on eBay (eg, item 232879025831) and is usually called '16V1F/2F Farad Capacitor Module 2.7V 10F Super Capacitor With Protection Board' It will cost you about £5 delivered. The board uses six 2.7V, 10F capacitors, plus some protection circuitry (mounted on the rear of the board). Note that the rated voltage is 16V, so you mustn't exceed this.

So how do we connect the capacitor pack? It sounds straightforward – just wire the pack across the DC/DC converter's output, and it will then run the lights when the dynamo isn't producing any power. The trouble is, when charging, the capacitor pack will load the system to an extent that the lights stop working! What's needed, therefore, is a series resistor high enough to limit charging (so that the front and rear lights still work), but not so high that the capacitor pack takes unduly long to charge. The value of resistor will be dependent on the LED lights being used: that is, the resistor's value should be selected through experimentation. With the components described above, a 47Ω resistor gave good results – when the capacitor pack was charging, the lights were a little dimmer than normal, but it took only 2-3 minutes to fully charge the pack.

So how long do the lights stay on for after you come to a stop? Starting with the capacitor pack at zero voltage, three minutes of slow riding gives sufficient charge to run the:

- Steady headlight at adequate brightness for 1 minute; it remains visible for 1½ minutes total
- Flashing tail light at good brightness for 4½ minutes, it remains visible for 8 minutes total.

There's an important point to note here. Despite both the head- and tail-light being sourced from the same Banggood product (ID: 1127241), the flashing red LED will work down to a much lower voltage than the non-flashing white headlight. This is lucky – when you're stopped, it's more important to have a tail-light than a headlight.

If you want the lights to stay on longer when you are stopped, you could add another capacitor pack. The resistors that feed each pack will need to be double the value of the resistor used for just the one pack. Again, some juggling of this value might be needed to achieve the best outcome.

Mounting

On a bike, it is the switches and connectors that are most likely to cause problems when the machine is exposed to the elements, so I chose to have neither. The system runs all the time, and all the wiring was made just the right length to suit the bike on which it was being installed. To make the electronics completely weather- and vibration-proof, I mounted the system in a short (100mm) length of 42mm plastic pipe, potted the boards in epoxy and then covered the ends with plastic pipe caps – see Fig.8. Ironically, the potting compound cost more than the electronics – but it should also make the system very reliable.

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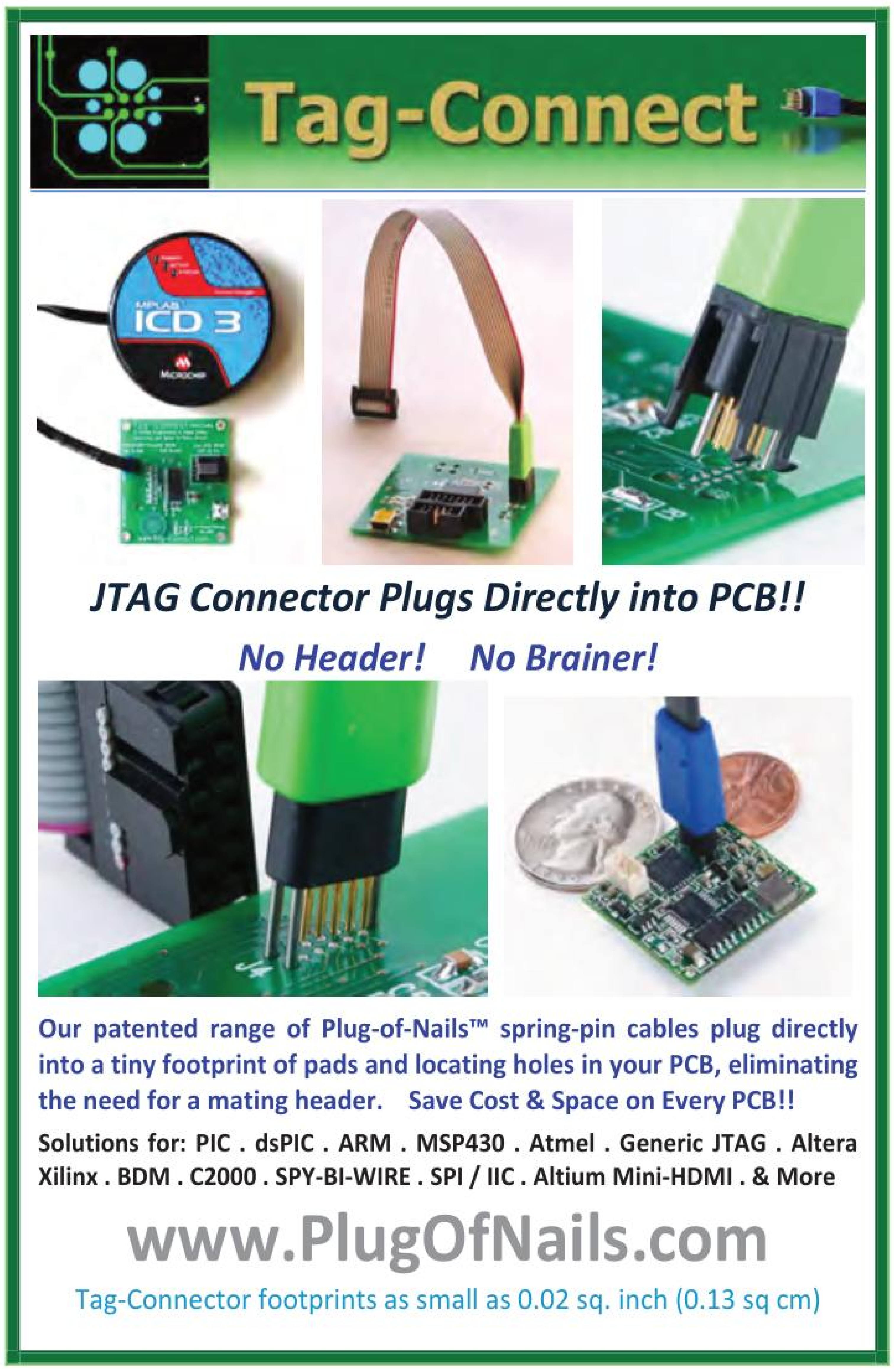

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Lucy's Lab

Dr Lucy Rogers explores the frontiers of electronics for hobbyists and makers

Lucy's IoT

I am good at copying stuff and following instructions – but I only read a manual if I really have to. I was one of those annoying school kids. I'm also a rote learner – I can repeat various scientific laws, such as Ohm's, Boyle's and Avagadro's, but without actually understanding the underlying principals. And while all that is great for passing exams and getting a metaphorical pat on the head from the teacher, it's not been ideal for my adventures in electronics.

RIP R-Pi

But fortunately, the maker community is all for learning (and sharing our mistakes). One of my early mistakes was discovering that the GPIO pins on a Raspberry Pi only work with logic-level signals. This means they can only supply 3.3V and a few mA of current from each pin. That's enough to power one or two LEDs, but connect a 3V motor to the pins and it's bye bye Raspberry Pi.

I quickly learnt about open-collector drivers and realised that I wanted to use them all the time. At that stage, my 'electronics hobbyist' skills were quite low, and in my first attempt I soldered the diode in the wrong way round and got the transistor legs muddled up. I was making these open-collector drivers on Veroboard, which was a bit of a faff, so I decided to make my own PCB.

As easy as PCB

I had no idea how to make a PCB – here's the stages I usually adopt when trying something new …

1. Ask around to see who else has done the task in hand and how they did it.
2. See what free/inexpensive software is available – I may hate it.
3. Download some software and have a play.

I have found that 'having a play' is great, but it is something like a role-playing game: 'There are two options – which do you chose, Option A or Option B?' Three hours of hard work later and you inevitably find you made the wrong choice.

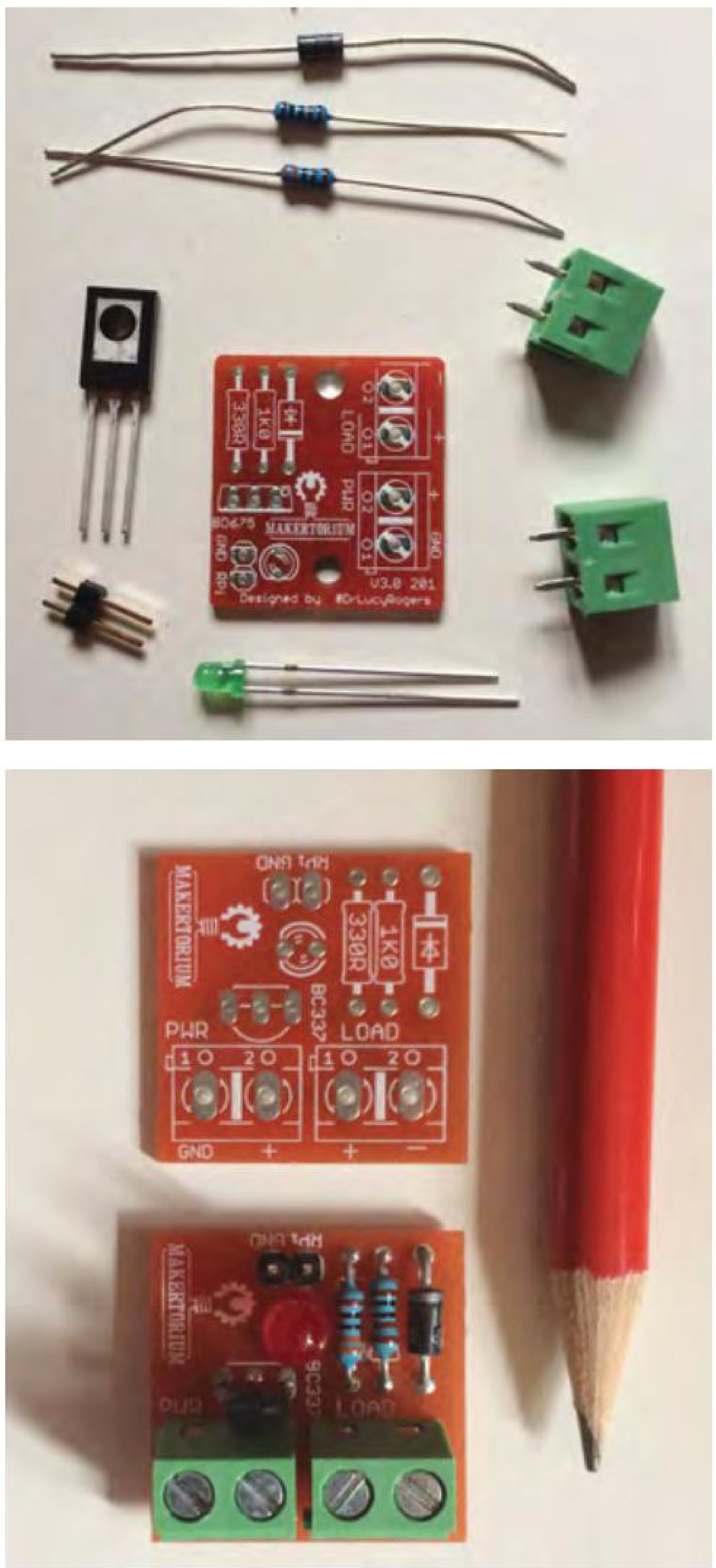

Fig.1. There's nothing quite like the satisfaction of designing and populating your own PCB –, even a relatively small and simple one like this general-purpose open-collector driver board.

Also, there are numerous unfathomable questions – for PCB design this includes: what is a 'rat's nest' and will autoroute actually route everything automatically and correctly? Why can't I do x, y or z? And so, the next steps become:

4. Get stuck
5. Google
6. Swear
7. Give up, phone a friend, or keep trying on your own with the Internet. Or even, 'Read The ... Manual'.

Giving up is usually only temporary – I'm ~~pig-headed~~ … *tenacious!* So I usually get a version of the thing I wanted, eventually.

I finally designed a PCB, got the files ready and sent them off to a PCB manufacturer. When the PCB's turned up in the post, I must admit I ran around with excitement and maybe even let out a 'squee'!

WIre it up, write it up

I'd like to claim that I write up my lab notes as helpful 'how tos' and publish them on the web to give back to the community. However, it's probably more so that I can really understand what I did, and when I want to do it again I have clear instructions (I did mention that I like following instructions, didnt' I?).

Here's my first PCB write up: **www.bit.ly/2Qk12X2**. After the success of my first PCB, I wanted to make something else. However, a component I wanted to use wasn't in the libraries. So I also learnt how to make a component, a 'device' in Eagle: **www.bit.ly/2wYrVqE**

If it can go wrong… it will, and an expensive 'n00b' mistake I made in my early days of electronics was discovering that 'ground' is not always 0V. I fried two £30 sound adaptors before I realised this. However, that is a lesson now learnt.

Rabbiting on

One of the most complex things I've made is a pair of *SMS Bunnies* – see: **www.ibm.co/2O7u7TY** – these were the result of my mum asking for a way to send a quick 'I'm thinking of you' message to her grandchildren, without them having a phone or being connected to Wi-Fi.

I used a cheap Chinese SIM800L module and a pay as you go SIM card. My Mum could then text the kids' *Bunnies* (the words were never

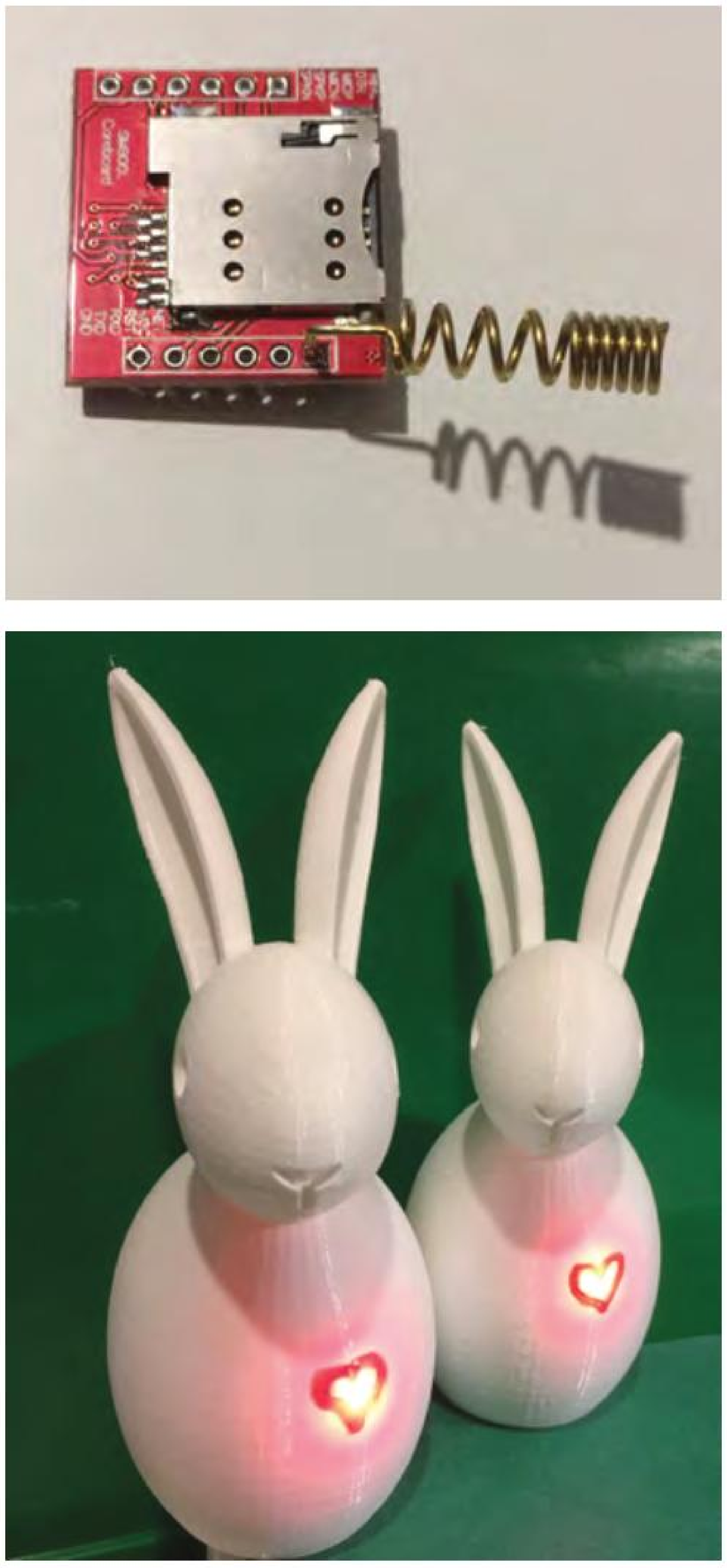

Fig.2. My SMS Bunnies project used a cheap Chinese SIM module (top) to enable my mum to send a message to her grandchildren.

read) and a light inside the always-connected *Bunny* would turn on. The kids could press their bunny's tail and my Mum would get a pre-programmed text message back. The idea was relatively simple. However, I eventually discovered the module is very fussy about the supply voltage – a little bit too high or too low and it powers off. My debugging skills have improved far quicker than any of my other electronics hobbyist skills!

Cheap is not always cheerful

I have now decided that rather than using the cheapest Chinese components, I will try and select a breakout or developer board produced by a company such as Adafruit. Although these are a lot more expensive, they have already had many of their problems debugged and they often come with software libraries and tutorials (I'm back to following instructions again!). This also helps when I write up my builds – 'Follow the instructions for the breakout board given here …' is much easier than 'get a multimeter, hold your breath, try 1,484 different things, including turn it off and on again, and hopefully you will work out why it went wrong.'

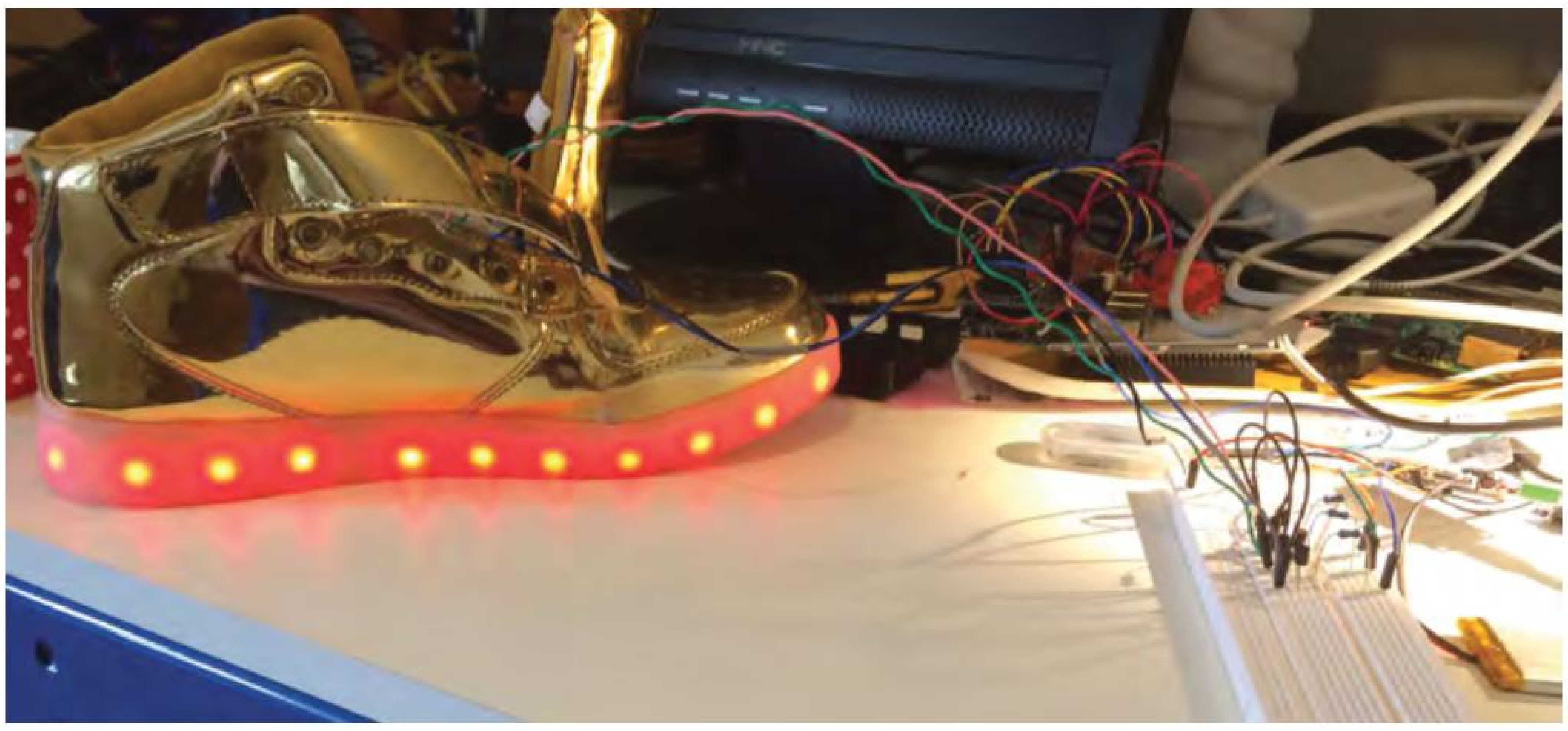

Fig.3. On the bench – customising my LED Cheerlights Boots

These boots were made for twinkling

One of my projects I enjoyed the most was making *Cheerlights Boots*: **www.bit.ly/2MZZN12**

I bought a pair of LED boots off the Internet, which included RGB LEDs, a battery and a switch. When they were turned on they'd flash or change colour. I wore them to a geek conference called 'Thingmonk' (**http://thingmonk.com**) and was challenged to hack them so that they could be controlled by tweets.

Many people around the world use the twitter hashtag **#Cheerlights** to control some form of lighting display. This is particularly popular at Christmas, when decorations change colour whenever someone tweets **#Cheerlights** and a colour. It's great to know that your one tweet is changing thousands of things around the globe.

I pulled out the potted electronics and battery from the boots, and put my own electronics in. I made the Wi-Fi in the boots connect to my phone hotspot so that they could receive and respond to the tweets. This was great fun. Then I had another idea – maybe one that was a bit too big for my boots. I wanted a red LED on the boot to always point North. The rest of the LEDs would be another colour. To do this I needed to change the RGB LEDs for addressable LEDs.

I had to heat the boot to peel the glue off so I could get in and change the LEDs, which were on a flexible strip that nicely curved around the toe of the boot. I got the electronics working (OK, sort of working, the compass modules are a bit of a pain and don't like being tilted too much). The boots worked on the lab bench – just in time for me to go off to another geek event.

I checked the boots in the hotel room. All good. The next morning, I put them on and walked down to breakfast. Only to realise with a sinking feeling that the cracking noise coming from my foot was the LED strip breaking into twenty different pieces. It was flexible enough to curl round the toes – but I had completely forgotten that when one walks, one needs to bend between the ball of the foot and the toes. The strip wasn't able to cope with that. So, electronics win, common sense fail.

Most of my projects have involved a connection to the Internet in one way or another, and I have been following the progress of the Internet of Things – IoT. There are many examples of items that are connected to the Internet that maybe shouldn't be, and can cause big security issues; or can be solved more easily just by looking. However, my items are all a bit flippant. Or as someone once called it – I have made the 'Internet of Tat'!

FIg.4. Puss n' Cheerlights Boots

Plug

I've written a foreword to an excellent book, *Robot: Meet the Machines of the Future* – £14.99, published by DK. Aimed at the 9+ age group, it gives an introduction to the history of robotics, defines a robot and explores how they work and profiles some of the best bots around.

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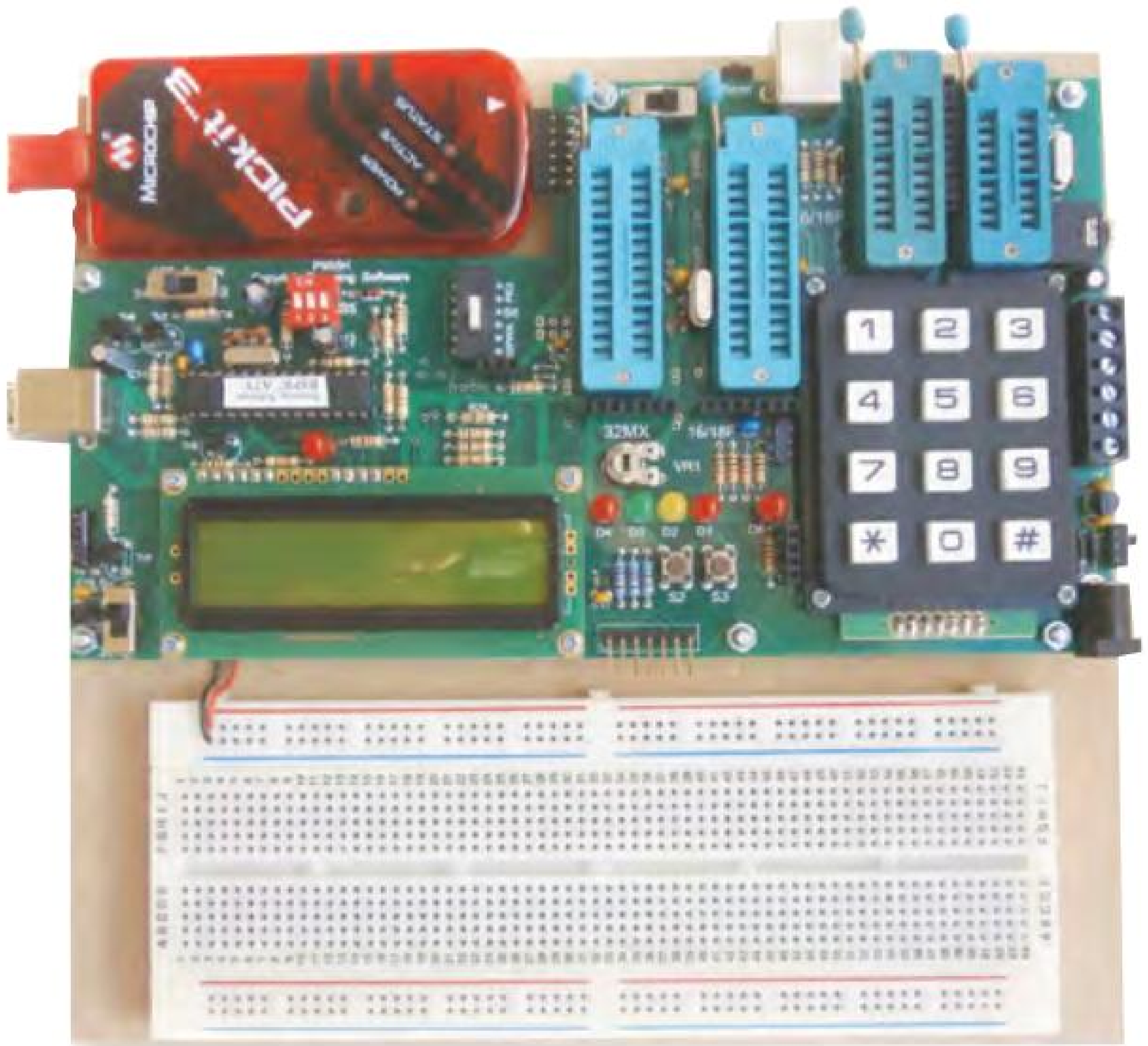
P955H PIC Training Circuit

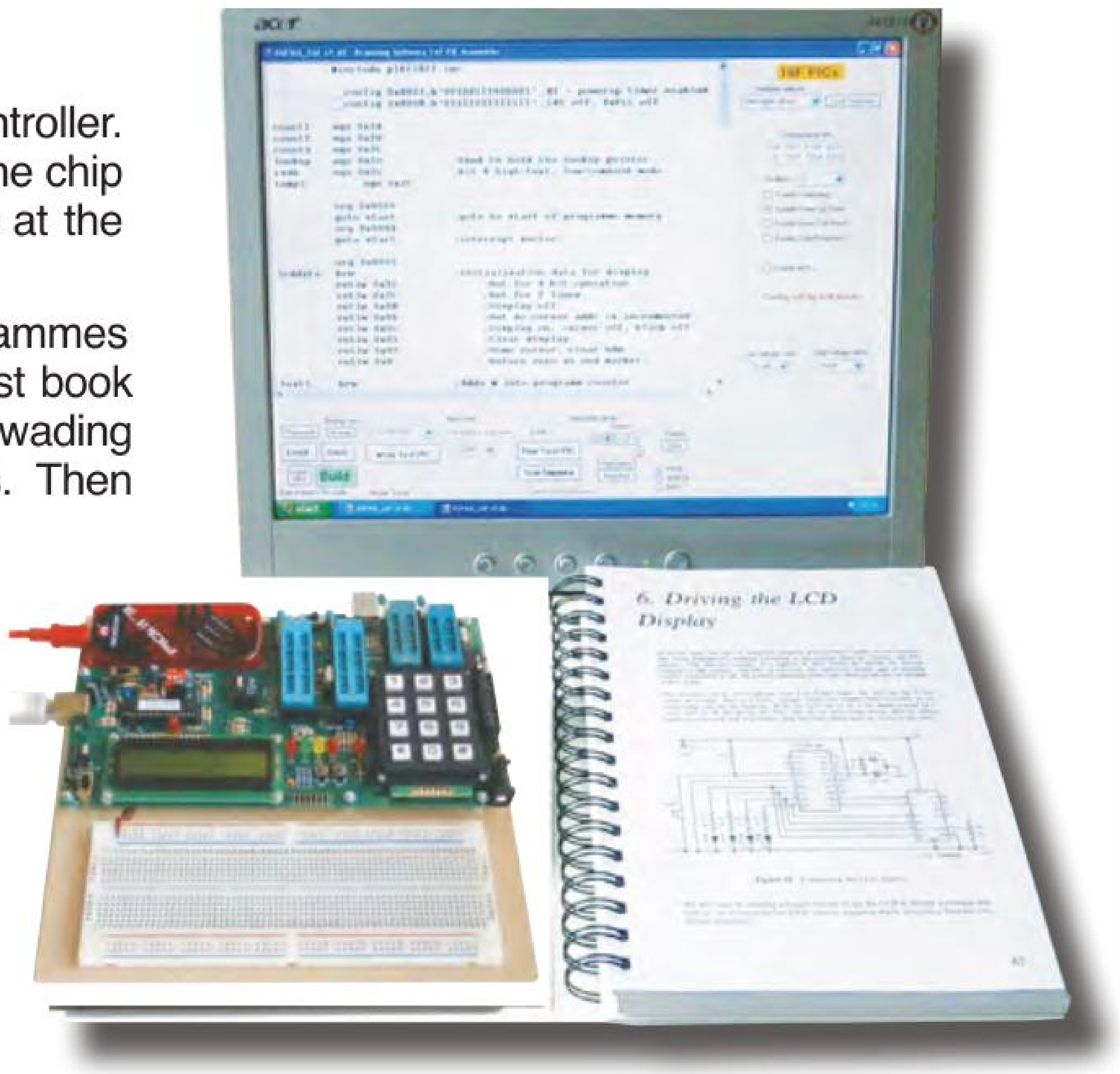
by Peter Brunning



When you are first learning about PICs, whether you are a complete beginner or an experienced programmer, you need an uncomplicated system which allows you to learns about PICs without getting bogged down in system procedure. That is why we created the P955H PIC training circuit and our own PIC assembler. In the first book we learn about PIC programming using the Brunning Software PIC assembler BSPWA but in chapter 3M there is an introduction to the Microchip assembler MPASM X. All our assember text will run in both systems so from there on if you wish you can use MPASM X. Likewise we start by using the on board PIC programmer to write the code into the PIC but if you prefer, plug on a PICkit 3 and use that. The P955H training circuit has the flexibility to be what you need as your learning process advances.

The P955H training circuit has been designed to work with both 32 bit and 8 bit PICs. The idea is to start learning about PICs using assembler with 8 bit PICs. Then learn C with 8 bit PICs, study serial communications using 8 bit PICs, and finally study C programming using 32 bit PICs. It is a simple approach to a subject that has no limit to its ultimate complexity.

The Brunning Software P955H PIC Training Course



We start by learning to use a relatively simple 8 bit PIC microcontroller. We make our connections directly to the input and output pins of the chip and have full control of the internal facilities of the chip. We work at the grass roots level.

The first book teaches absolute beginners to write PIC programmes using assembler which is the natural language of the PIC. The first book starts by assuming you know nothing about PICs but instead of wading into the theory we jump straight in with four easy experiments. Then having gained some experience we study the basic principles of PIC programming, learn about the 8 bit timer, how to drive the alphanumeric liquid crystal display, create a real time clock, experiment with the watchdog timer, sleep mode, beeps and music. Then there are two projects to work through. In the space of 24 experiments two project and 56 exercises we work through from absolute beginner to experienced engineer level using the latest 8 bit PICs (16F and 18F).

The second book introduces the C programming language for 8 bit PICs in very simple terms. The third book Experimenting with Serial Communications teaches Visual C# programming for the PC so that we can create PC programmes to control PIC circuits.

In the fourth book we learn to programme 32 bit MX PICs using fundamental C instructions. Flash the LEDs, study the 16 bit and 32 bit timers, write text to the LCD, and enter numbers using the keypad. This is all quite straightforward as most of the code is the same as already used with the 8 bit PICs. Then life gets more complex as we delve into serial communications with the final task being to create an audio oscilloscope with advanced triggering and adjustable scan rate.

The complete P955H training course is £254 including P955H training circuit, 4 books (240 × 170mm 1200 pages total), 6 PIC microcontrollers, PIC assembler and programme text on CD, 2 USB to PC leads, pack of components, and carriage to a UK address. (To programme 32 bit PICs you will need to plug on a PICkit3 which you need to buy from Microchip, Farnell or RS for £43).

Prices start from £170 for the P955H training circuit with books 1 and 2 (240 × 170mm 624 pages total), 2 PIC microcontrollers, PIC assembler and programme text on CD, USB to PC lead, and carriage to UK address. (PICkit3 not needed for this option). You can buy books 3 and 4, USB PIC, 32 bit PIC and components kit as required later. See website for details.

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CIRCUIT SURGERY

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BY IAN BELL

Introduction to Circuit Simulation with LTspice – Part 2

LAST MONTH, we started looking at circuit simulation using SPICE (Simulation Program with Integrated Circuit Emphasis), a de facto industry standard for computer-based analysis of (mainly) analogue circuits. I often use the free SPICE simulator LTspice in *Circuit Surgery* articles to illustrate circuit operation, and recently we decided to make the simulation files available on the *EPE* website so that readers can try the simulations for themselves. These articles will provide an introduction to SPICE simulation and using LTspice. The software can be downloaded from Analog Devices: **www.bit.ly/2nsvKzT**, although it was originally developed by Linear Technology (LT), hence the name.

We also discussed some of the history of SPICE and the reasons for its development and continued widespread use. We went on to look at the types of analysis it can perform and discussed the relative merits of simulation versus building and testing physical prototypes. In fact, many circuit designers use both approaches – simulation can help ensure that a design is likely to work the first time you build it, but cannot easily account for every aspect of reality. On the other hand, at least in some cases, simulation can more accurately represent the parameters of system, and their range of possible variation, than a single (or small number) of prototypes. This is particularly true if the prototypes are implemented in a physically different form from the final version (eg, solderless breadboard for prototyping a PCB).

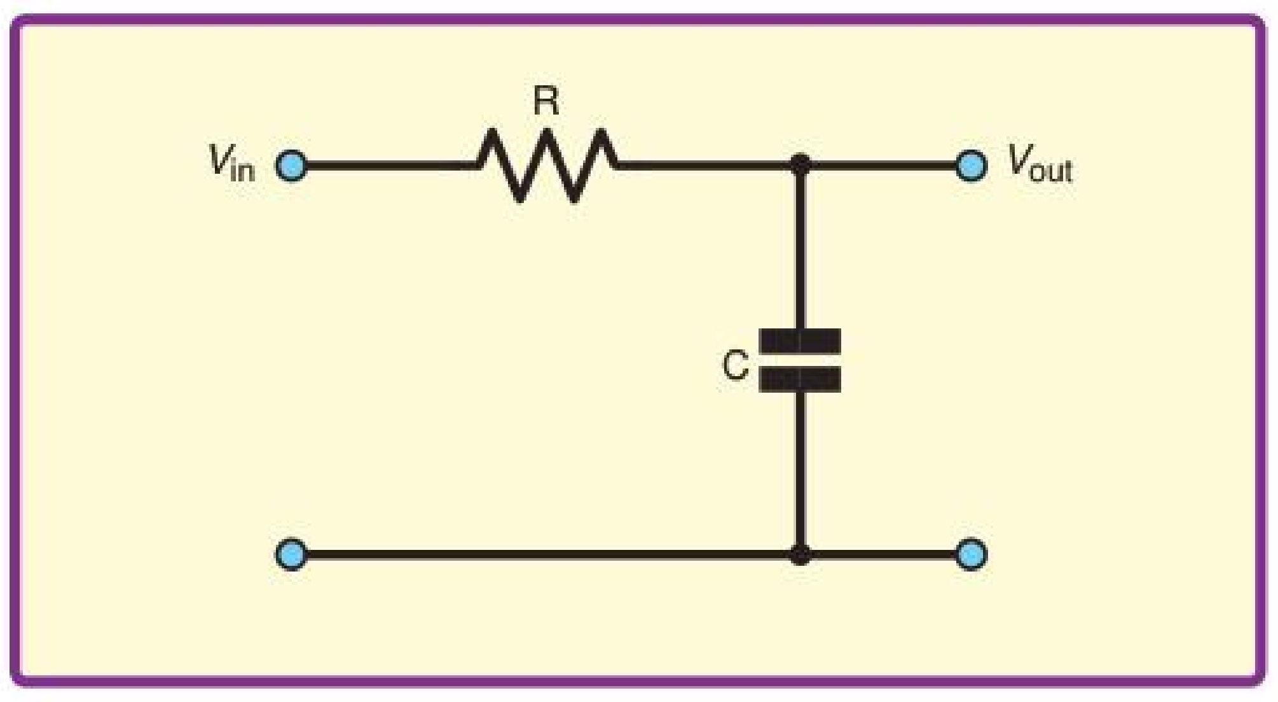


Fig.1. RC circuit simulation example.

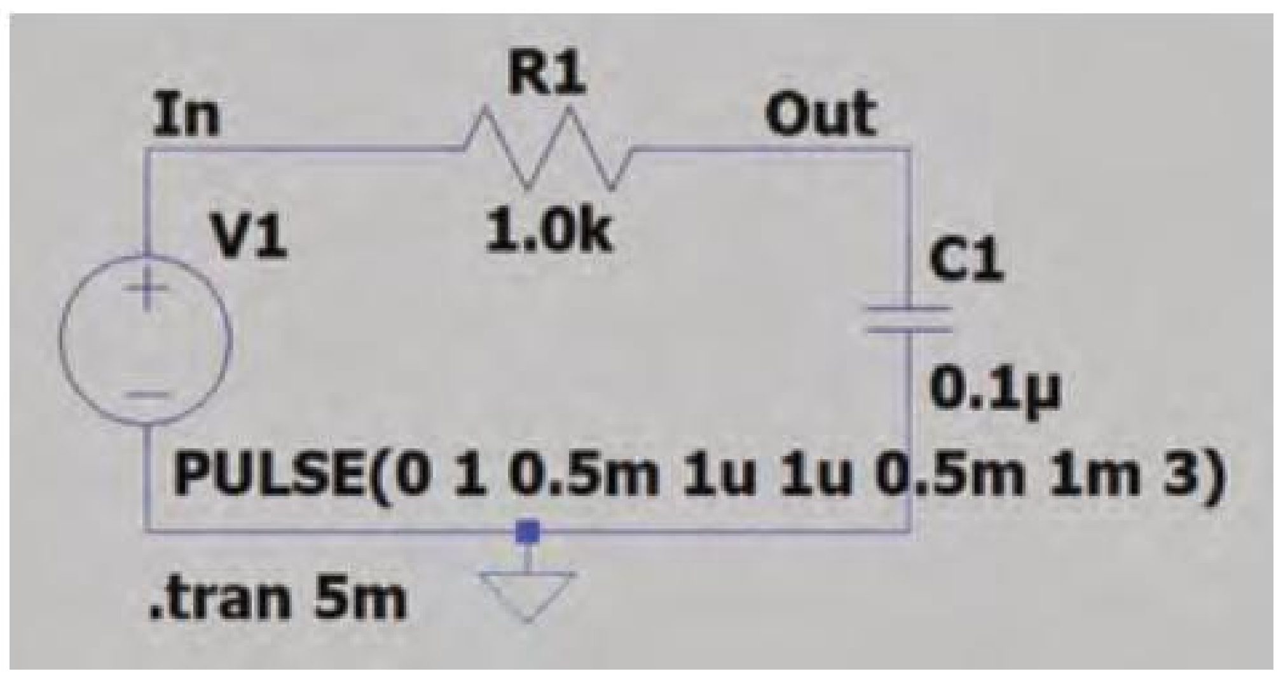


Fig.2. LTspice schematic used last month for transient simulation of the circuit in Fig.1.

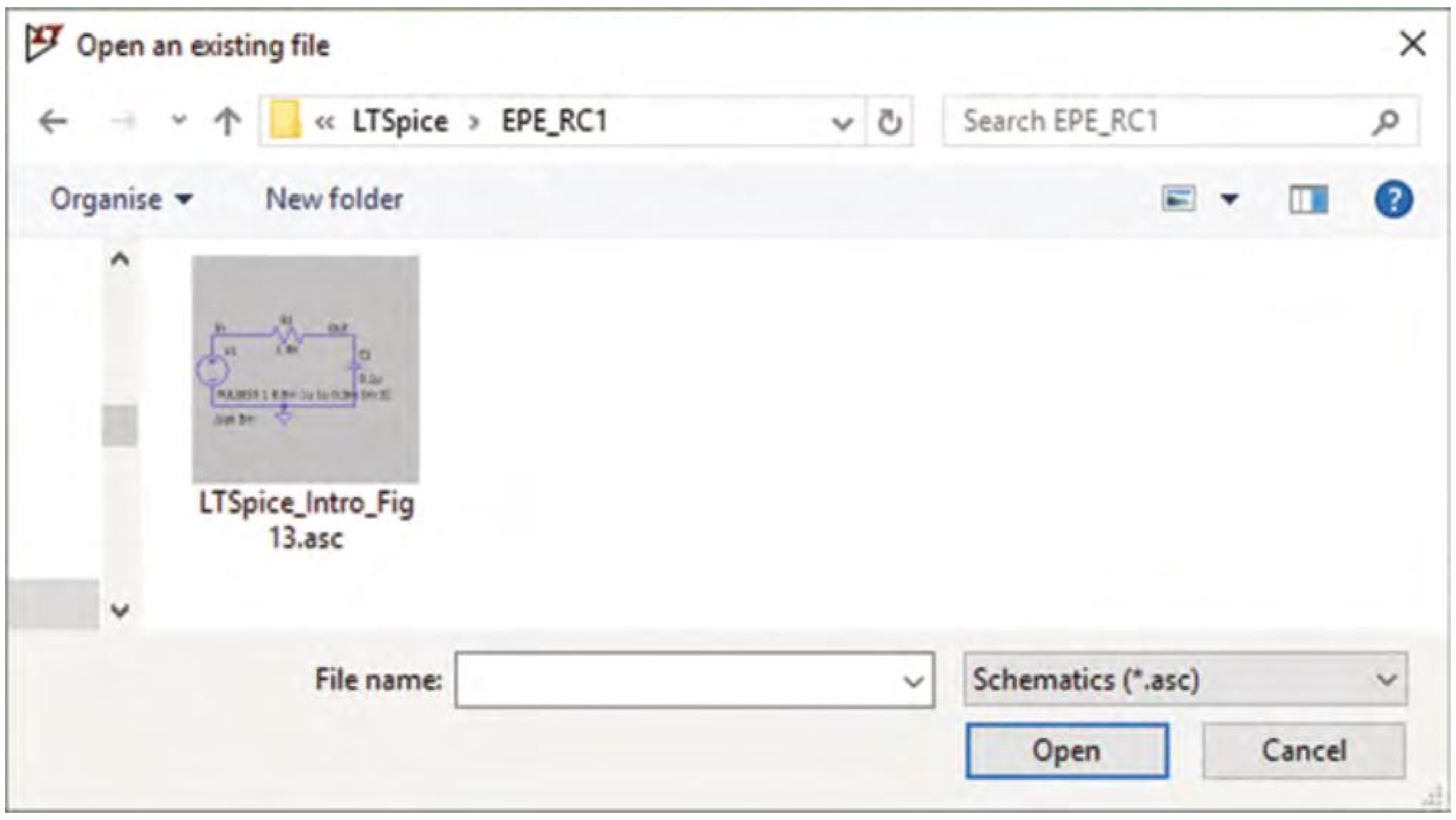


Fig.3. LTspice file open dialog

Although SPICE was originally developed for IC design, it is now also widely used for discrete designs. This is not limited to circuits built from basic components such as resistors, capacitors and transistors – you can also simulate a wide of range of specific ICs, including op amps, comparators and regulators. Many manufacturers provide models of their devices to facilitate SPICE simulation (explore the Add Component function in LTspice to get some idea of what is available). LTspice comes with an extensive library of components, which, as you might expect, are mainly ICs from Linear Technology and Analog Devices. However, generic SPICE models from other manufacturers may be downloaded and used – this may require use of netlist files, which we will introduce shortly.

In addition to specific design work, SPICE simulation is useful for learning about electronics. You can simulate circuits and check the results against your ideas and calculations. Although this cannot replace the experience of building and testing real circuits, it does allow you to quickly explore variations in circuit structures and component values, and make (virtual) measurements, which would require expensive test equipment or lengthy procedures for a physical circuit.

Simulation example recap

In the second half of last month's article we started looking at the details of how to use LTspice, and this month we will continue this process. The first example we are using is the RC circuit shown in Fig.1. As explained last month, when simulating you should have some idea of what to expect from the simulation so you are less likely to be fooled by user errors or simulation issues. In accordance with this approach, we described some of the theory relating to the circuit in Fig.1, which we will now briefly recap.

If we apply a fixed DC voltage, V_{in} to the circuit in Fig.1, then the capacitor will charge through the resistor. V_{out} will vary with the elapsed time (t) since V_{in} was applied, such that:

$$V_{out} = V_{in}(1 - e^{-t/RC})$$

We can simulate this variation of voltage with time in SPICE using a transient simulation, which was the example we looked at last month.

Simulation files

The LTSpice files discussed in this month's *Circuit Surgery* are available for download from the *EPE* website.

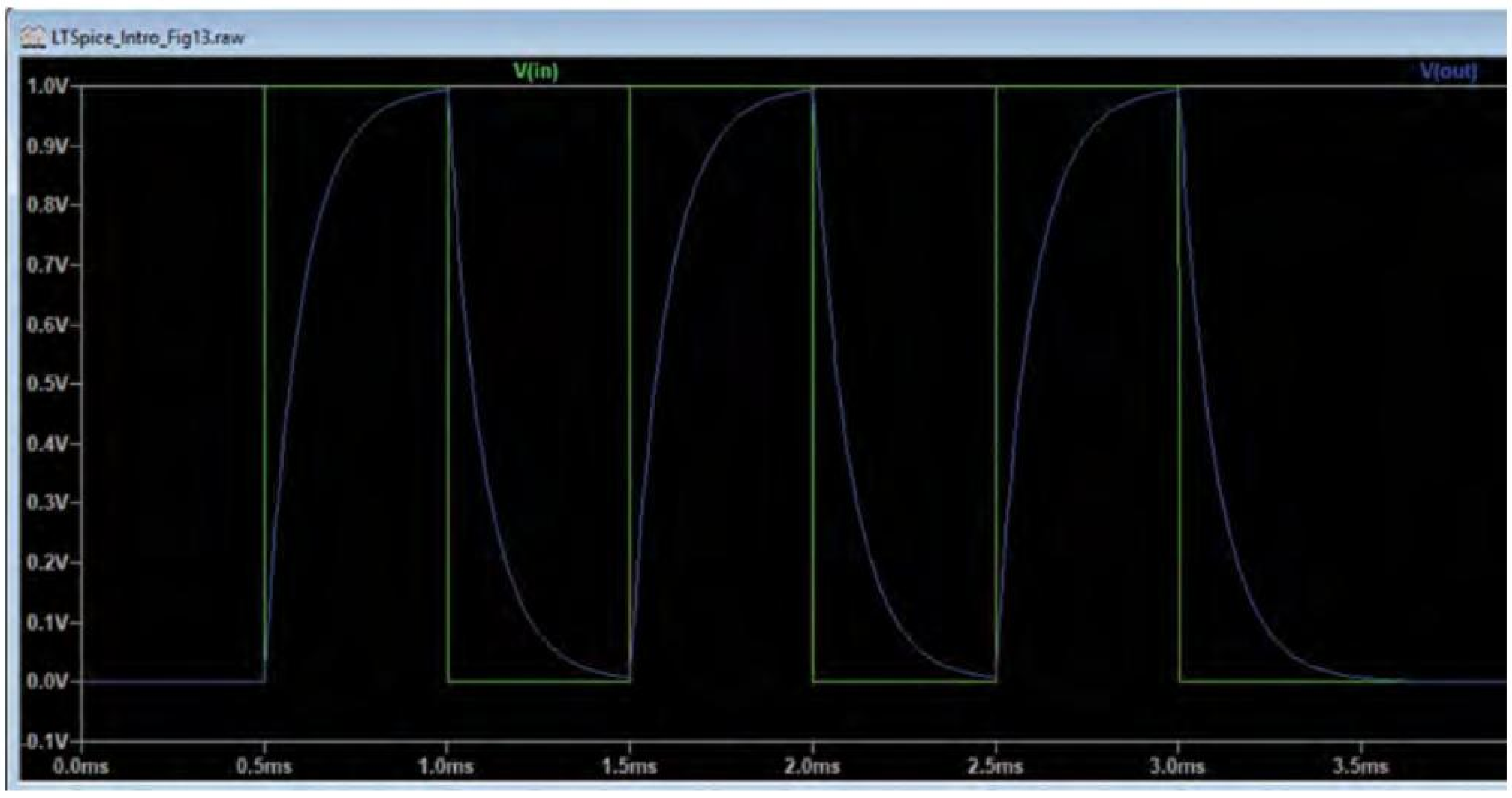


Fig.4. Transient simulation results from last month's example simulation

With an AC input applied, the circuit in Fig.1 acts as a low-pass filter with a cut-off frequency (f_c) which is given by:

$$f_c = 1/2\pi RC$$

At this frequency the magnitude of V_{out} is $0.707V_{in}$. To look at the variation of gain with frequency in SPICE, including finding the cut-off frequency, we need to perform an AC analysis. The circuit in Fig.1 is not sufficient for the simulation – we need to provide the inputs and define what we will be measuring, a virtual form of setting up test gear in a lab.

LTspice files

The LTspice schematic we used last month for transient simulation of the circuit in Fig.1 is shown in Fig.2. We got as far as displaying the waveform, but did not investigate the results in any detail. We will return to the step-by-step instructions after taking a quick look at the files that LTspice uses. Some details of commands are provided for reference, but if you are following the example wait until the Example Continued section before actually trying the steps described.

LTspice schematic files have the extension `.asc`. You can open then using `File > Open` from the main menu, or by using the list of recent files that appears on the File menu. The file open dialog is shown in Fig.3 – note the drop-down box of file types next to the file name. This should default to Schematic, but you will need to change it to open other types of file (and change back again for schematics). The schematic file (`.asc`) is a text file describing the schematic drawing. As such, you could view it, and even edit the text, but it is very unlikely that you would want to do this.

If you look in a folder containing a simulated LTspice schematic, you will also find a file with the same name and a `.raw` extension. This file, which is referred to as a waveform file, contains the simulation result data created when a simulation was run. It is a binary file, so unlike the schematic, you cannot look at the content directly. However, you can open it with LTspice, which will provide the same waveform viewing window you get from directly running a simulation. If you didn't save the plot settings (see below), opening a `.raw` file will give you a blank waveform window, from which you can proceed to add waveforms as you wish, see last month's example (Fig.4).

As just noted, to be able to reopen waveform data with the same graph configuration you also need a plot settings (`.plt`) file. If a `.plt` file has the same file name as the waveform file (with `.raw` extension) then it will be used automatically to configure the waveform display. The file can also be manually loaded using Plot `Settings > Open Plot Settings` from the main menu, but note that this menu option is only available when a waveform display window (such as the one shown in Fig.4) is selected. If you want to save your own waveform settings then use `Plot Settings > Save Plot Settings`. The plotting settings files are text files.

Along with the `.raw` file you will also find an `.op.raw` file, which contains results – specifically DC operating point data. LTspice does a DC operating point analysis before running other analyses, because simulation algorithms require it, but it can also be performed on its own.

After running a simulation there will be a `.log` file, which contains information about the simulation, including error and warning messages. It can be viewed using `View > SPICE Error Log`. You may need to look at this file if there are problems with a simulation, or to see the results of certain analyses that produce text output, but otherwise most of the information relates to simulator operation, and may not mean much to users new to SPICE.

When we provide LTspice files on the *EPE* website these will mainly be the `.asc` schematic files. The `.raw` files are potentially large and are generated by running the simulation, so we do not need to upload these. In some cases the configuration of the waveform display window may take some effort – to get the best presentation of the results, or simply reproduce the graphs as published in EPE. In such cases we will provide the `.plt` plot settings file.

Listing 1

```
* D:\LTSpice\EPE_RC1\LTSpice_Intro_Fig13.asc
C1 Out 0 0.1µ
R1 Out In 1.0k
V1 In 0 PULSE(0 1 0.5m 1u 1u 0.5m 1m 3)
.tran 5m
.backanno
.end
```

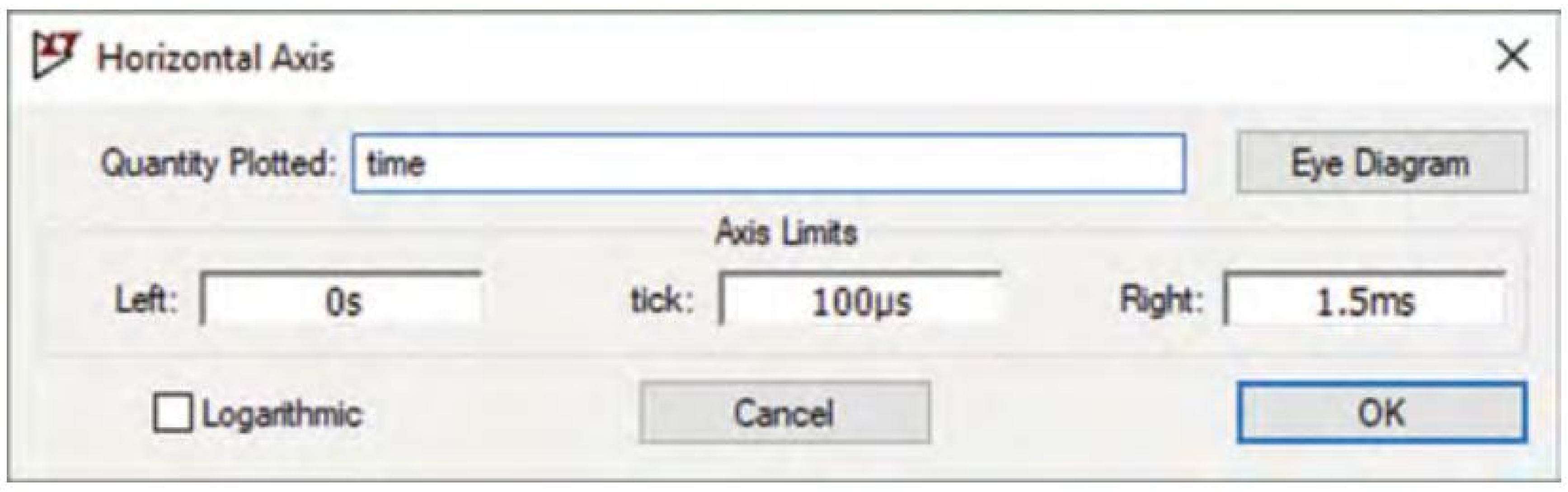
The SPICE netlist

The `.asc` file, and the schematic it describes, may seem like the input to the simulator – that is the obvious perception from a user drawing it then running the simulation, as we did last month. However, the 'real' input is the SPICE netlist. This is another text file, which when using schematics is automatically generated by LTspice. You can view the netlist from the main menu using `View > SPICE` Netlist (when a schematic is selected). This will open a text-viewing window. The netlist for Fig.2 is shown in Listing 1 below.

This file can be saved as a text file, typically with extensions `.cir` or `.net` by right clicking on the title bar of the text window – but there is no need to do this unless you want to use the netlist elsewhere, or manually edit it. This is unlikely for users new to SPICE, but it is helpful to have some idea of what is happening when you work with a SPICE circuit. Also, if you start looking for simulation models of components not automatically included in the LTspice library, you are likely to need to work with netlist text files. LTspice can open and simulate directly from netlists without schematics, but you have to code everything – for example, there are no dialogs for configuring simulations.

You may wonder why there are in effect two descriptions of the circuit (schematic and netlist). Recall that SPICE was developed in the 1970s – the netlist format dates from then, when modern GUI-based (graphical user interface) schematic editors were not feasible. The schematic graphics are not part of the SPICE 'standard' – different software packages will handle this in different ways. The netlist is standard, or at least a significant proportion of it is – some SPICE tools will have additional features or commands, which may not be understood by others.

The general syntax of the SPICE netlist is straightforward, although some individual items may seem complex due to the number of options



Quantity Plotted: time

Left: 0s

tick: 100µs

Right: 1.5ms

☐ Logarithmic

Fig.5. Horizontal axis settings dialog

and amount of possible detail. The netlist format is influenced by the fact that SPICE was originally developed in the programming language Fortran, with computers that used punched cards as input (one card per line). Terms such as 'SPICE deck' and 'model card' continued to be used long after punched cards had disappeared. The first character on a netlist line (and hence on the punched card back in the 1970s) is important as it specifies what is on that line, as defined below:

*	**Comment** – the line is ignored by the simulator
`Letter`	**Component** – letter indicates type – R: resistor, C: capacitor...
`.`	**Simulation directive** – the line contains a command to the simulator, for example `.trans` to run a transient simulation
+	**Continuation** of previous line. '+' is removed and rest of line is considered part of prior line.

The letter designating a component's type is followed by a unique identifier, which together form its individual component (or instance) name – eg, R1. This is followed by the connection details and the values of component parameters (eg, the resistance of a resistor) and other information. Each SPICE directive has its own syntax, although they follow similar patterns. Details are provided in Help, however, for basic use of LTspice you do not need to know the text forms of these commands since they are created for you by the user interface. For example, last month we set up the transient simulation using the Edit Simulation Command dialog, which produced the directive text (`.tran 5m`) to place on the schematic. Similarly, the SPICE code to specify the pulses from V1 voltage source was set up using another dialog.

For more advanced use, even when using schematics, it is sometimes necessary to enter SPICE directives directly. This can be done using the relevant button, or `Edit > SPICE directive`, and placing the text on the schematic. Similarly, you can just add plain text to your schematic using the text button, or `Edit > Text`. This is useful for adding titles, notes and other information not automatically included with components. Such text appears as comments in the netlist.

To finish our quick look at the netlist, note that the last two lines contain directives which do not appear on the schematic. These are automatically added to every netlist LTspice creates from a schematic. The `.ends` directive fairly obviously marks the end of the netlist. The `.backanno` directive instructs the simulator to include information in the simulation data which enables LTspice to display currents when users click on symbol pins on the schematic. For more detail on netlist format, the General Structure and Conventions page of the LTspice User Manual is helpful.

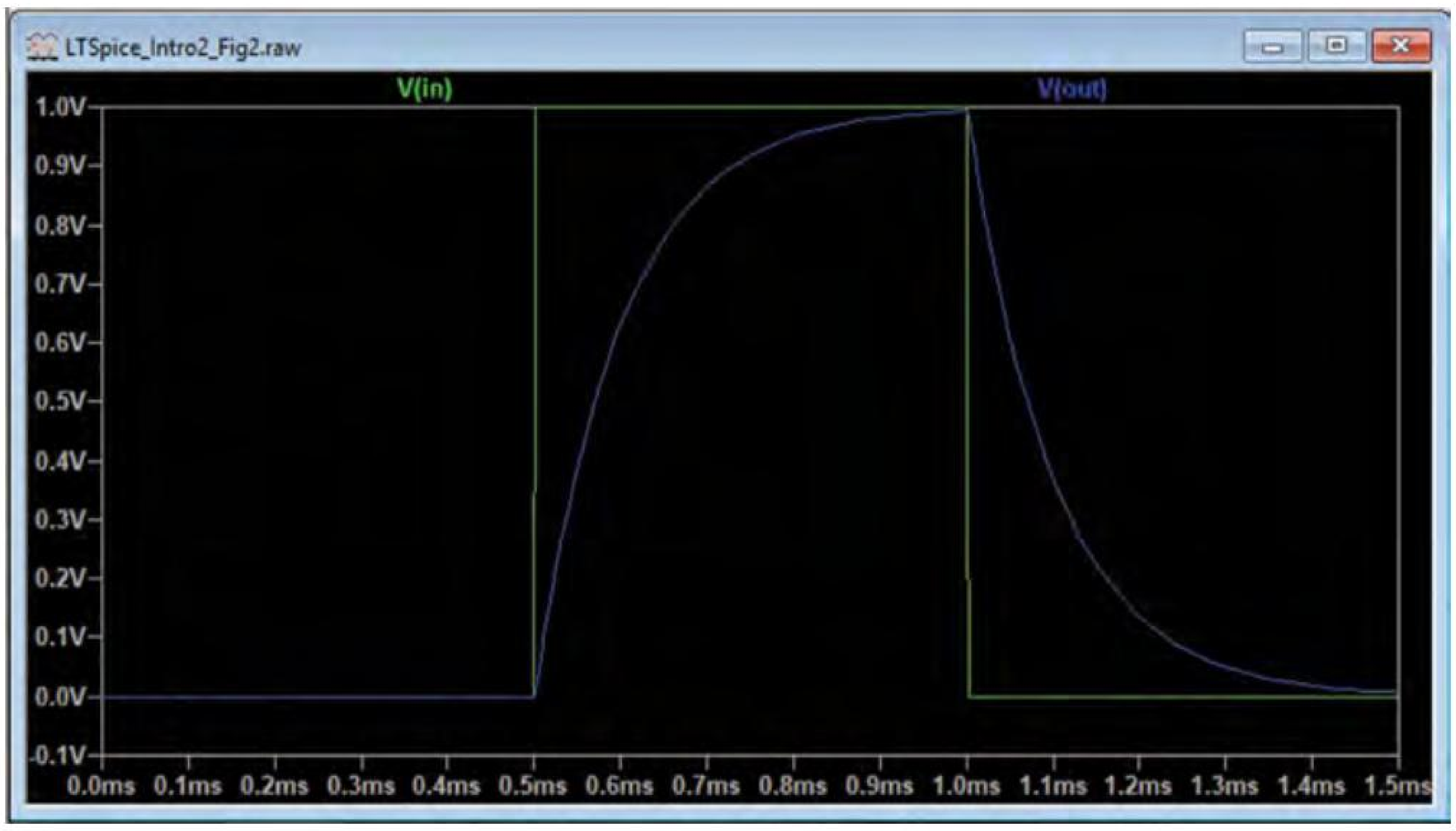
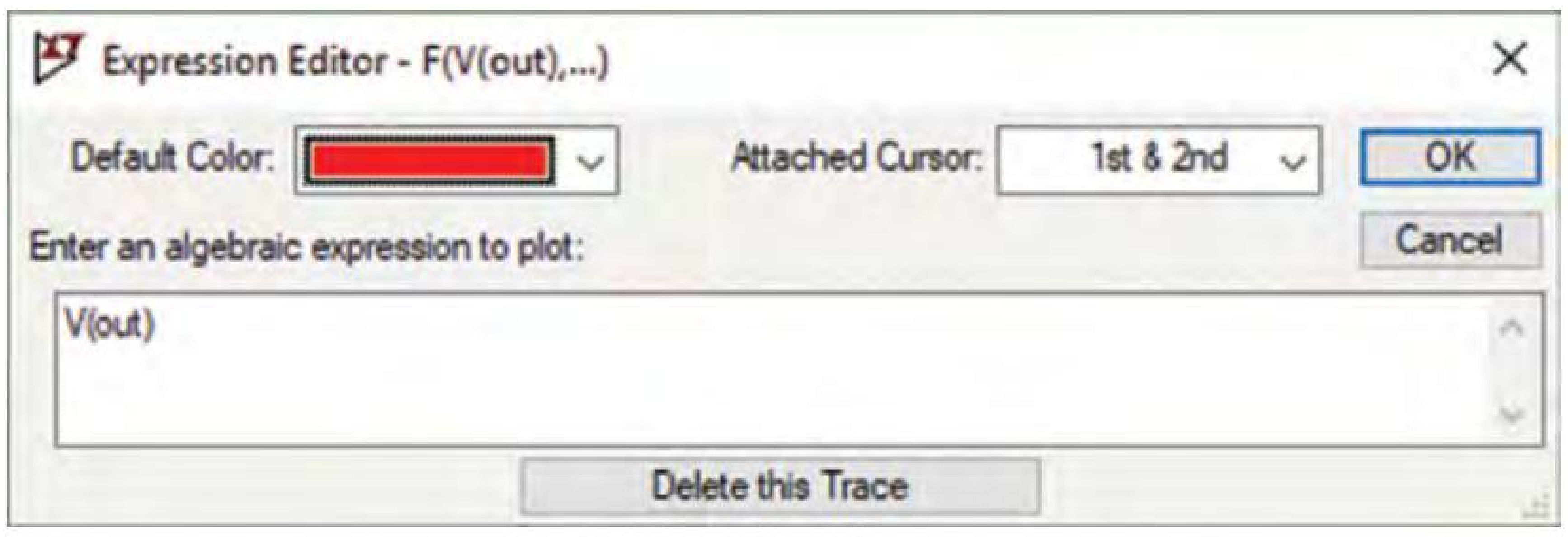


Fig.6. Waveform with modified time-axis settings



Default Color: 🟥

Attached Cursor: 1st & 2nd

Enter an algebraic expression to plot:

V(out)

Fig.7. Expression Editor dialog used to change waveform signal, graph colour and attach cursors

Example continued

If you followed the instructions last week the you will probably have a folder containing the `.asc`, `.raw`, `.op.raw` and `.log` files. You may have the `.plt` too, if you found the save plot settings menu item. Alternatively, download the `.asc` and `.plt` files related to this month's article from the *EPE* website into a new folder.

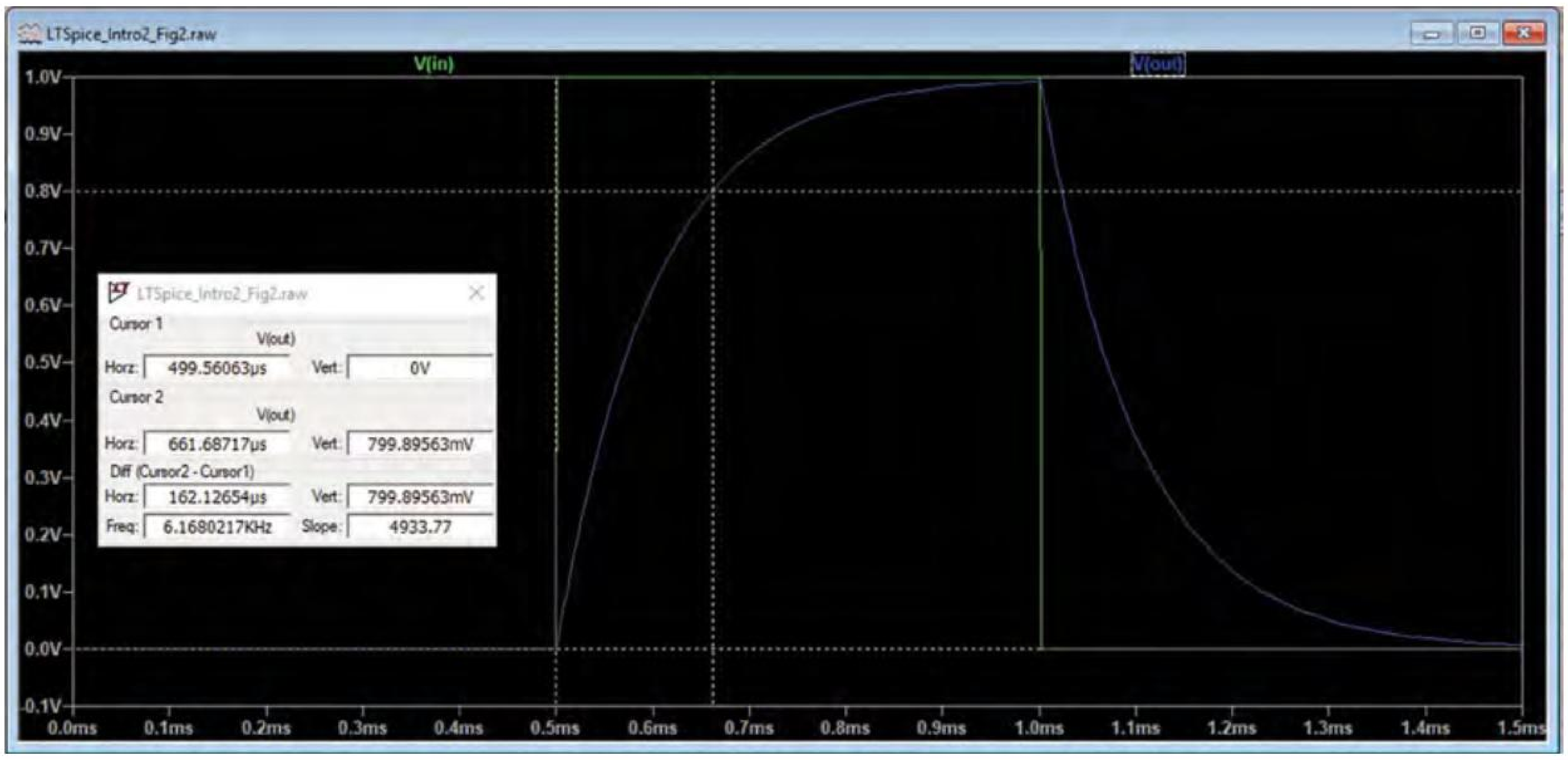
Start LTspice and open your schematic (`.asc` file) using `Open > Schematic` or the recent files list. Then do `Simulate > Run`. If you have the plot settings file then the waveforms should appear as in Fig.4, otherwise right click in the black background of the graph area and select Add Trace. Select V(in) from the list that appears and click OK. Repeat the process, selecting V(out). If you do not already have a plot settings file click on the tab for the waveform file to make sure it is selected and do `Plot Settings > Save Plot Settings` from the main menu.

You should now have both the schematic and waveforms open, as shown in Fig.2 and Fig.4. In common with many applications handling internal windows, LTspice allows you to arrange these in various ways (eg, maximised, tiled, cascaded). The currently active window is selected by clicking in it or by using the tabs that appear under the menu bar.

As we have seen, the waveform display has functions accessed by right clicking. The main menu, which we used to add the waveforms, is obtained from the middle area of the graph, but once you have waveforms in place you can right click on the axes to change their settings. Notice that when you move the cursor over a graph axis the pointer changes to a rule-like shape. Right click on the time axis, which will open the Horizontal Axis dialog (see Fig.5). Change the value of Right to 1.5ms and the value of tick to 100µs. Note that you can use 'u' instead of 'µ' for micro values – you do not have to use the Greek letter directly. Click 'OK'.

The waveform display will change to something similar to Fig.6. The exact look will depend on the window size; for example, if the waveform window is too small to fit a set axis tick, LTspice will use a larger tick value than specified. Resizing the window (larger and smaller) will demonstrate this.

If you right-click on the signal name at the top of the waveform window you can change the waveform colour, change the signal displayed and attach cursors to help you make measurements. Note that the cursor



LTSpice_Intro2_Fig2.raw

Cursor 1

V(out)

Horz: 499.56063µs Vert: 0V

Cursor 2

V(out)

Horz: 661.68717µs Vert: 799.89563mV

Diff (Cursor2 - Cursor1)

Horz: 162.12654µs Vert: 799.89563mV

Freq: 6.1680217KHz Slope: 4933.77

Fig.8. Using the cursors to make a measurement

changes to a hand shape when the mouse is over the signal name. Right click on the `V(out)` signal name. In the Expression Editor dialog change the Default Color setting and select 1st and 2nd from the Attached Cursor dropdown box. Click 'OK' (see Fig.7).

You will see dashed white cursor lines appear in the waveform window and a separate window will open showing measured data (see Fig.8). When your mouse cursor is directly over one of the waveform cursors the pointer will change to the cursor number. At this point you can click and drag to move the cursor, observing the changing data in the measurement the window. The cursor follows the waveform as you drag it, allowing you to measure values at any point on the waveform. Since we added two cursors to the measurement window, it not only shows the values associate with each cursor, but also the difference between them, which is something that we often need when looking at waveforms. Note that the frequency associated with a time difference is calculated automatically and also displayed.

For this example we might be interested to measure how long it takes for the output to reach a particular voltage after the input switches. For example, the cursor positions in Fig.8 allow us to measure the time taken for V(out) to reach 0.8V. The cursors have been positioned at the input switching point and the point at which the output is 0.8V. The time difference can be read from the measurement window as 162µs. We can check this value against theory using the equation for V_{out} from above:

$$V_{out} = 1.0 \times (1 - e^{-162\times10^{-6}/1000\times0.1\times10^{-6}})$$
$$= 0.802$$

We find a good match. Note that the simulation is not necessarily perfect – SPICE uses numerical estimation algorithms to solve the circuit voltages and currents as time progresses. It is not using the above equation. This equation only applies to the well-known, simple RC circuit, but SPICE can also simulate an arbitrary combination of components for which no such standard equations are available. Accuracy may be improved by forcing the simulator to find more data points on the waveform and/or modifying the amount of data compression which it uses when saving the results. However we will not discuss these options in detail now. Close the measurement window using the 'X' – note that the cursors are removed.

Assuming you saved the plot settings earlier, the waveform graph can be restored to its original state. Use `Plot Settings > Reload Plot Settings` to do this. The waveforms should look similar to Fig.4 again. The waveform display now shows both waveforms on the same graph. Depending on what you are doing it may be better to use different graphs for different signals – this is particularly true if the signal levels are very different. For example, the details of the smaller waveform may be unreadable if plotted on the same graph as a larger one.

Right click on the `V(out)` signal name to open the Expression Editor dialog again. This time click on the Delete Trace button, which will remove `V(out)` from the graph. To create a separate graph (pane) right click on the background of the waveform and select `Add Plot Pane` from the menu. Do this a second time so that you have two blank graphs in addition to the one showing `V(in)`.

Last time, when we added signals we used the list available via the right-hand menu on the graph, but waveforms can also be added using the schematic. To make sure both are visible, click on the Tile Windows button from the main command buttons at the top of the LTspice window. Then click in the background of the top blank graph – this selects it as the destination for adding waveforms (there is a subtle change in the boundary line when a plot pane is selected). Now click on the tab for the schematic to select the schematic window. Move the cursor around over the schematic and note that the pointer changes to the shape of a voltmeter probe when you are near a wire. With the probe pointer visible, click on the `Out` wire – the output waveform will appear on the top plot plane. Now move back to the graph window and click on the middle (still blank) plot plane. Select the schematic again and move the cursor over the resistor. The pointer will change shape to look like a current clamp probe. With the pointer in this form click on the resistor. The current in the resistor will be displayed on the middle graph. The waveform window should look similar to Fig.9. You can save this plot arrangement to a different settings file using `File > Save Plot Settings As`. Then you can swap between the two views using `Plot Settings > Open Plot Settings`.

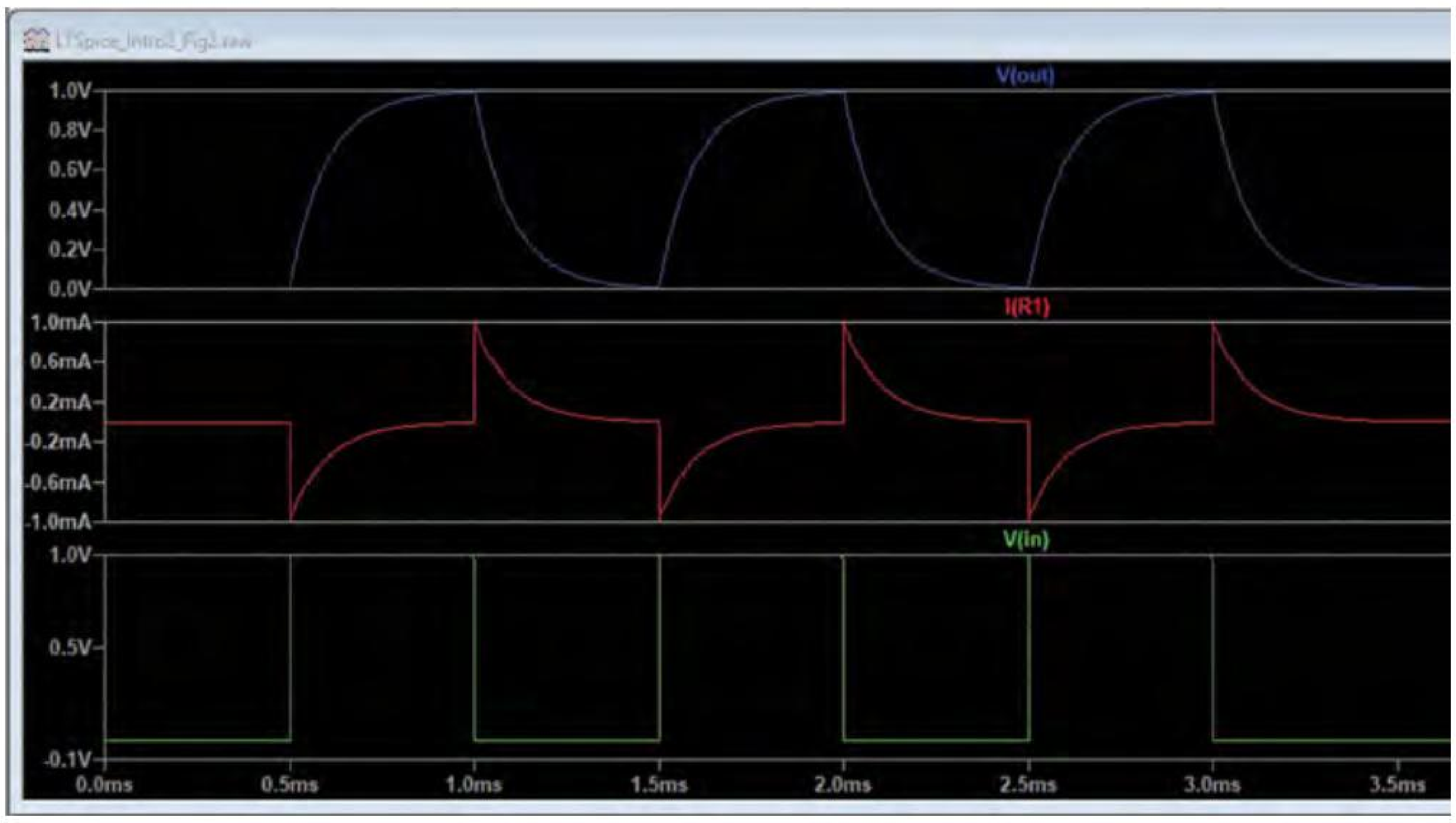


Fig.9. Waveform window with multiple plot planes

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AUDIO OUT

By Jake Rothman

Analogue synthesis – Part 4

This month we'll cover some more modules, making our way to a complete analogue synthesiser. However, first I've got to deal with some remaining technical titbits that I didn't quite have space for last month. I want to say a little about the important topic of matching transistors – specifically matching bipolar transistors, which is much the most common requirement.

Match making

Many electronic circuits using bipolar, or indeed any other kind of transistor, treat transistors as standalone building blocks with which you can build up larger sub-circuits and complete circuits. Every transistor is built to a specification so that you know when to use which type; for example, a small-signal, high-frequency or power device. However, within that specification there will be production tolerances, which means there will be small variations in the performance of same-type devices. In other words, even with the very sophisticated manufacturing processes of today's silicon foundries it's not possible to make exactly identical pairs of transistors – they are all a little different.

Often this doesn't matter. Providing you know to a reasonable degree of accuracy how a device performs then the circuit will work as designed. However, there are quite a few scenarios when these little differences do matter and the circuit design calls for transistors, typically pairs of transistors, which operate as closely as possible to each other. The long-tailed pair difference amplifier and current mirror are two of the best-known examples. We call the transistors in these examples 'matched pairs', because their performance parameters are carefully matched. Over the last three articles in this series you will have noticed I have used matched pairs in the exponentiator circuit, so now we will look at how to source these semiconductor twins.

There are basically two ways to find matched transistors. First, transistors can be bought as a matched pair, often supplied as one device, or as a sub-system in one integrated circuit. The well-known LM194 and LM394 are junction-isolated ultra-well-matched monolithic NPN transistor pairs with an order of magnitude improvement in matching over conventional transistor pairs. Plus, every time you use an op amp you are in effect buying a well-matched pair of transistors with the input difference amplifier section.

The second option is to manually check a batch of transistors and pick out devices that have closely matched parameters. This is a little more involved, but can be much cheaper and is an interesting task in itself, giving you greater insight into the operation of your circuit you have built.

So, how do we go about matching transistors? A first approach is to use the base-emitter voltage (V_{be}) matching circuit described last month in Fig.73. Mine was built using Veroboard and a 6-pin DIL socket, as shown in Fig.75. I also mentioned the Peak DCA75 – this is an excellent way of matching

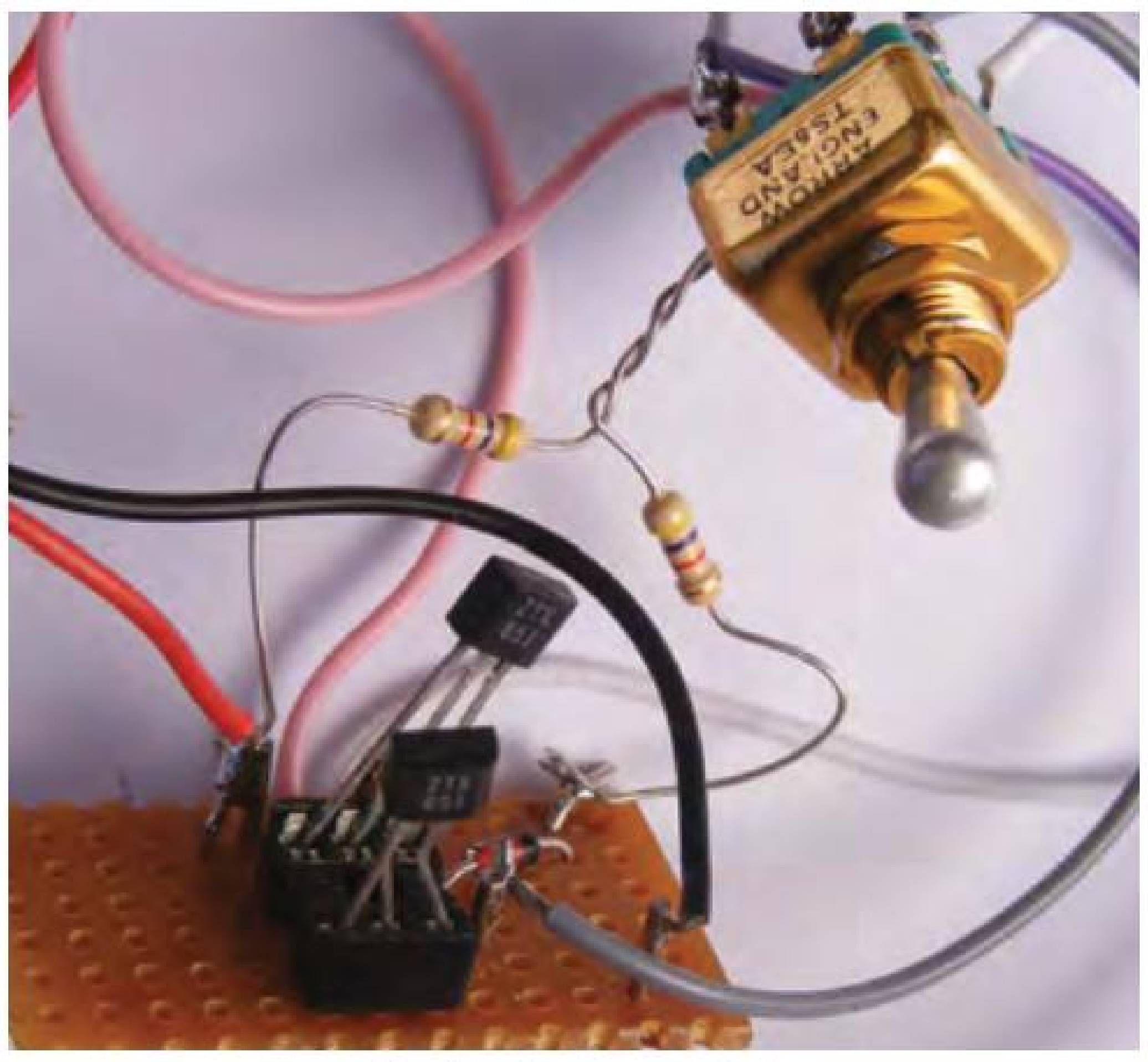

Fig.75. A quick 'lash-up' of the V_{be} test circuit. You could make a proper, thermally controlled housing for your design, as Soundtronics do: ***www.soundtronics.co.uk/mfos-transistor-matching/***

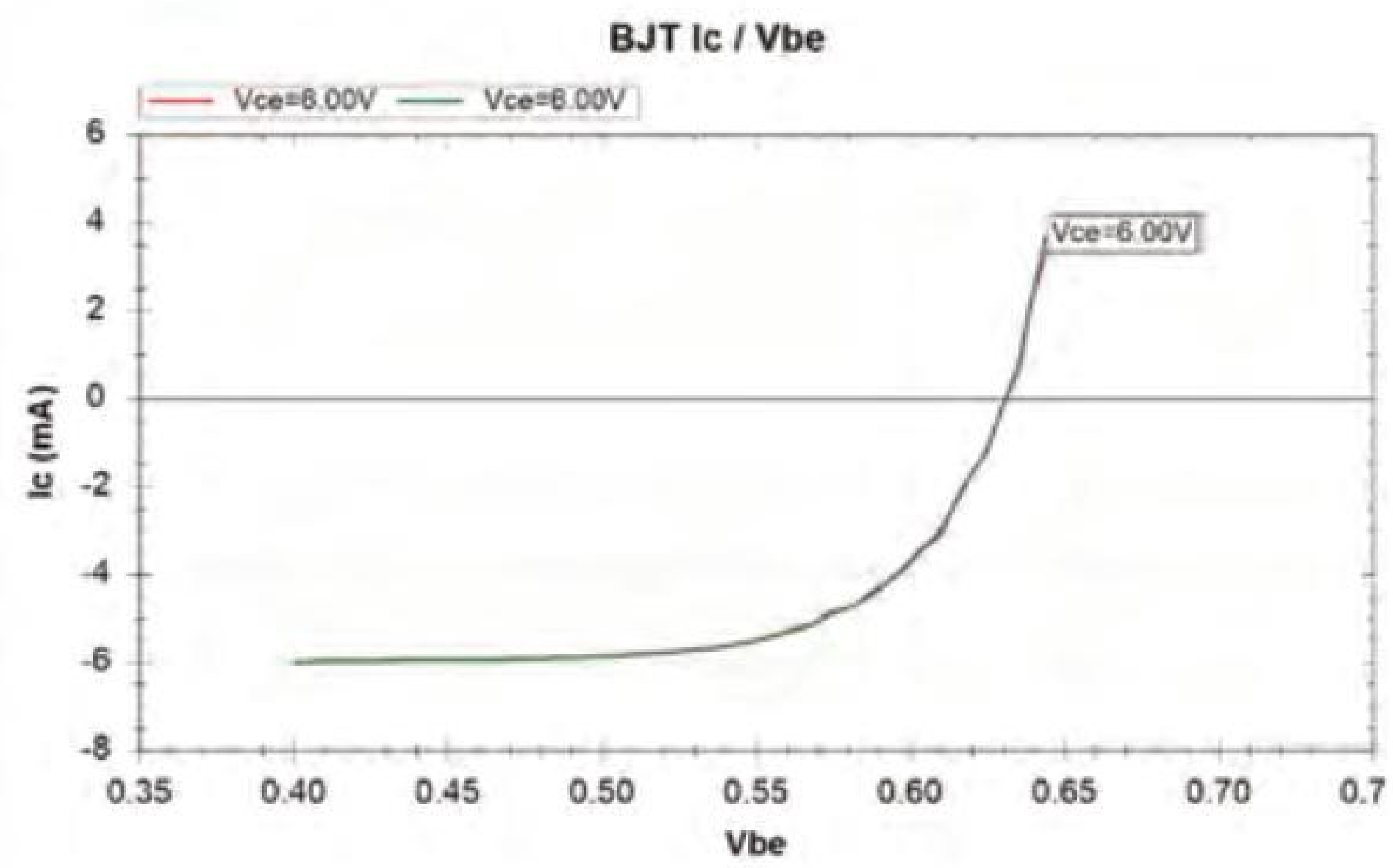

Fig.76. V_{be} vs I_c plot for a matched-pair. This is the SMT dual device HN3C51F-BL (marked DL). A photo of this component was shown in Fig.32 in Part 2. A cheap component is the Diodes Incorporated DMMT3904W-7-F with V_{be} values matched within 2% (11.5p, 100 off at Mouser).

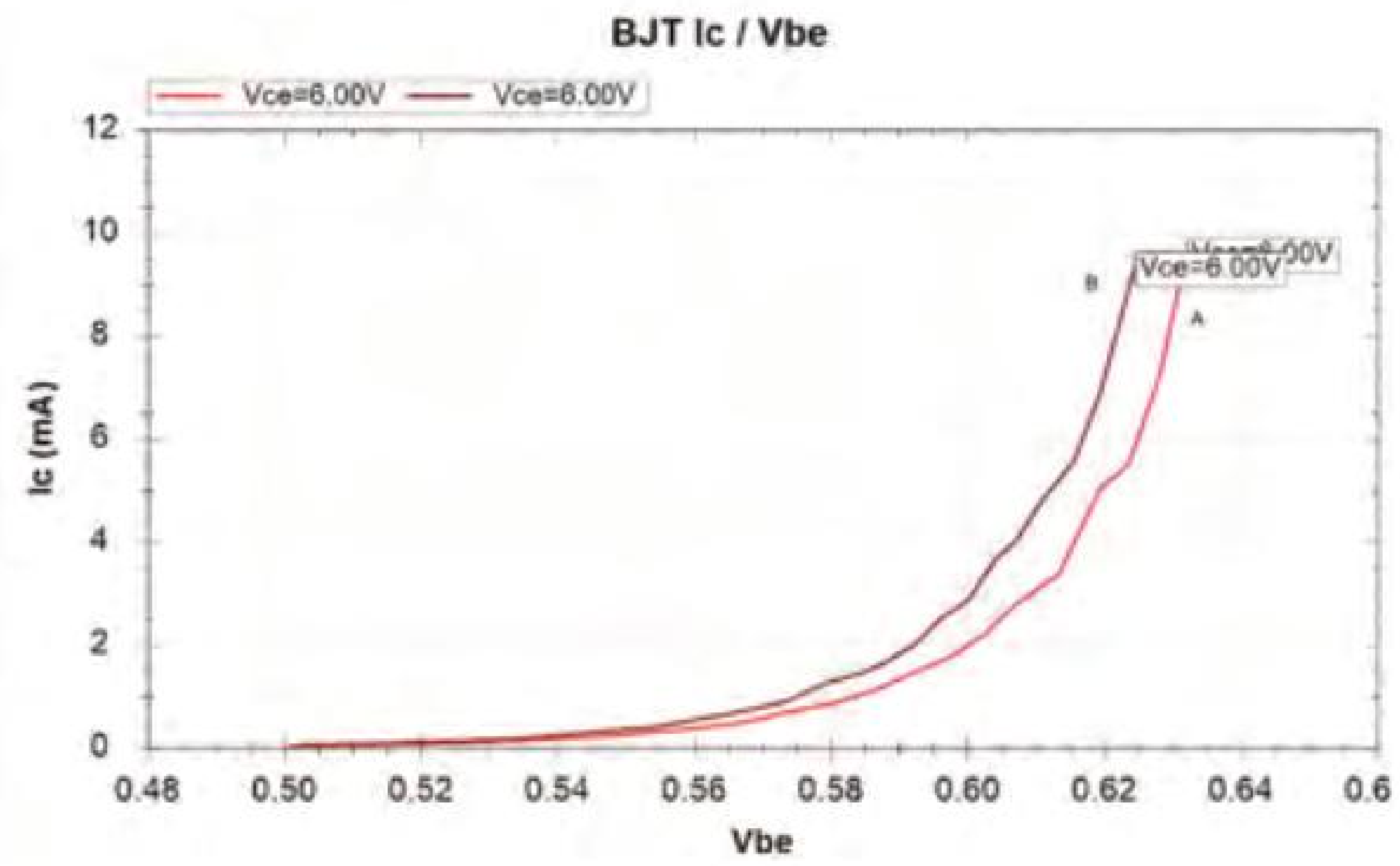

Fig.77. Plot showing a pair of randomly selected ZTX651 transistors.

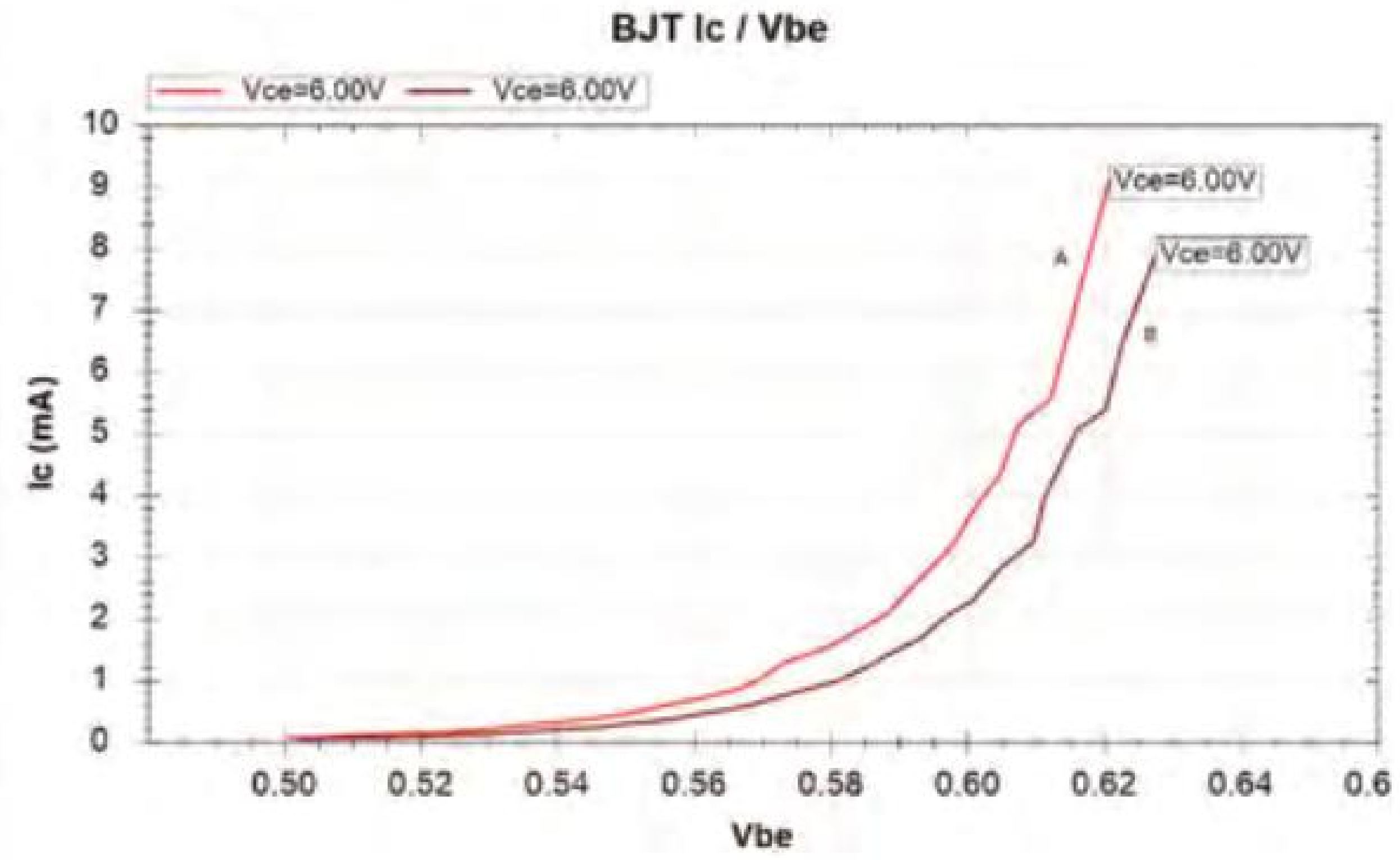

Fig.78. The effect of placing a finger on one of a matched pair of transistors causing a temperature difference of around 10ºC.

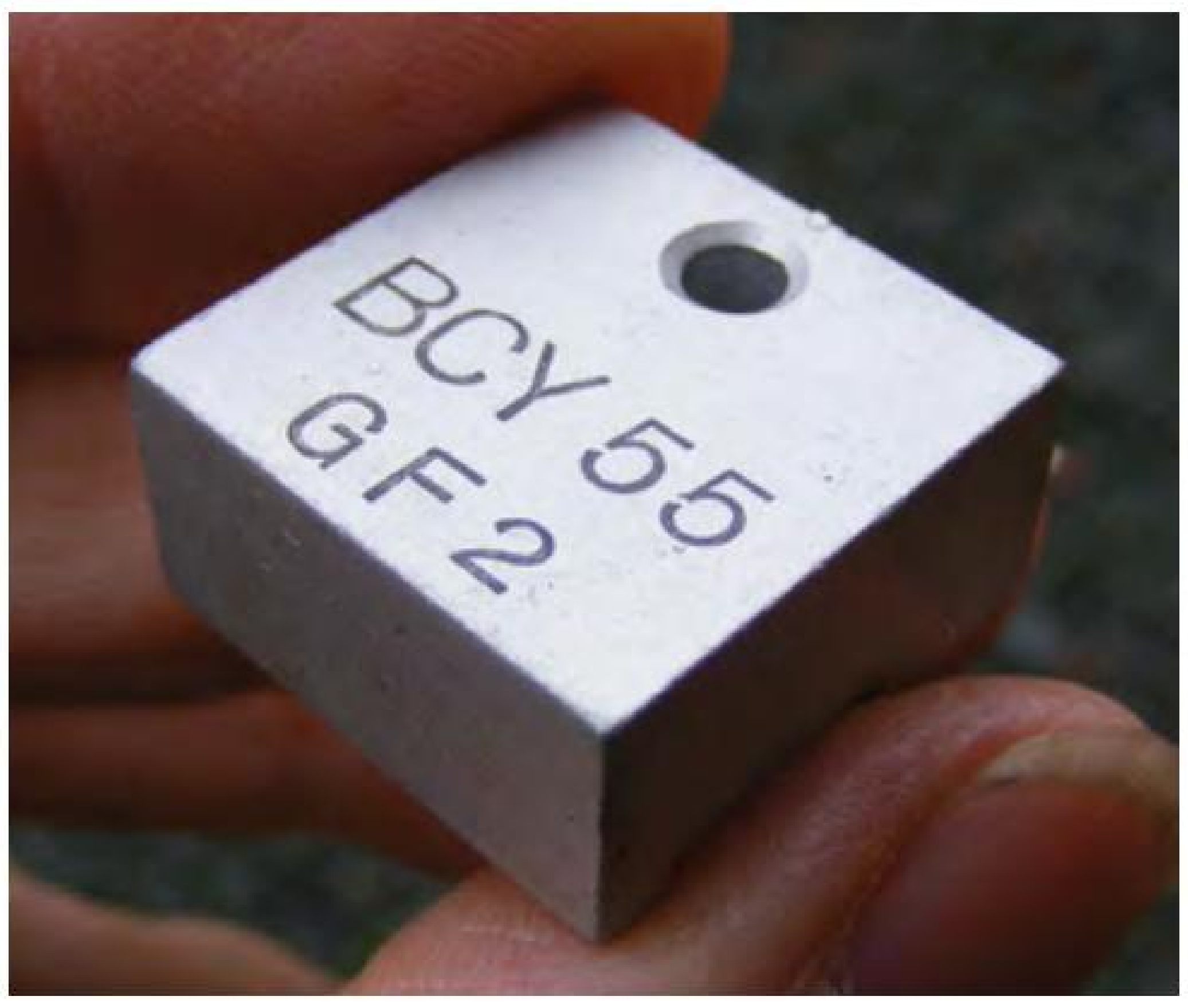

Fig.79. Mullard produced the BCY55, a big block of metal incorporating two matched transistors for low-drift DC amplifiers.

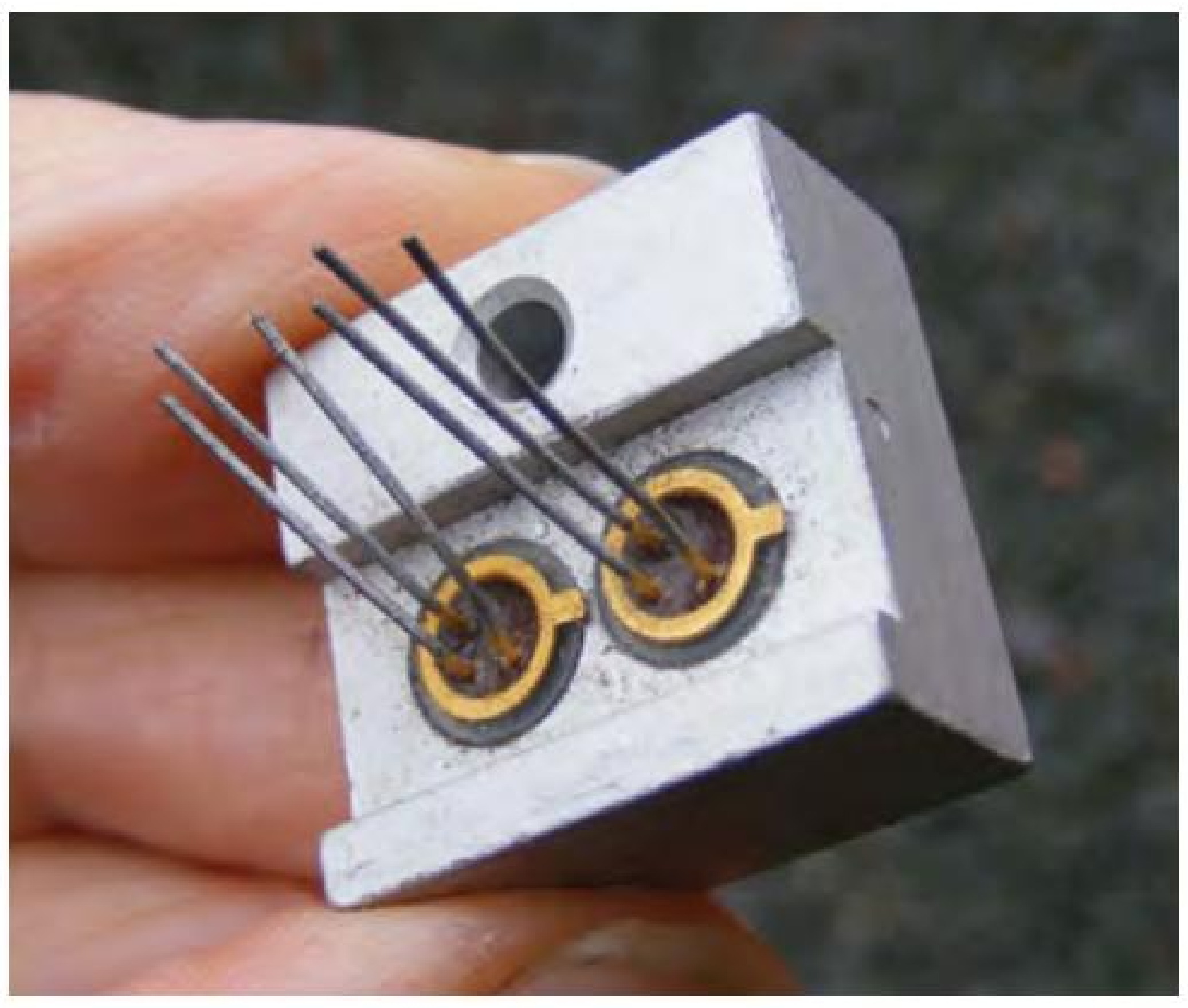

Fig.80. The underside of the BCY55 showing the two thermally aligned transistors.

transistors because it can plot the exponential V_{be} (base-emitter junction voltage) vs I_c (collector current) curve on a PC. An example is shown in Fig.76. Playing around with this indispensable piece of kit I was able to show very few of the transistors deviated from the exponential curve, confirming Molls assertion that it was inherent in the physics of the bipolar transistor. The few that did deviate were old unsoldered germanium types. No one in their right mind would use germanium devices in thermally sensitive circuits anyway! Some transistors with a high base-spreading resistance (r_{bb}) – a non-linear parameter rarely specified – flattened off at high currents. Maybe this was one reason the ZTX651 worked well in the exponentiator because its r_{bb} is low for a small transistor. According to the *The Art of Electronics* (p.495), the r_{bb} of a ZTX851 is 1.7Ω, so that device might well be worth trying. To be honest, I'm not entirely sure what the official technique for measuring it is; my results were much higher than those from *The Art of Electronics*. I opted to use the Peak Zen 50 tester, which can measure the forward resistance of a base-emitter junction and I found the ZTX651 was around 20Ω.

Mis-matching

Fig.77 shows a couple of randomly chosen ZTX651 transistors illustrating mis-matching in their V_{be}–I_c characteristic. A similar effect can occur if one of a matched pair of transistors is heated with a finger, as shown in Fig.78. TD Towers, who wrote the famous *International Transistor Selector*, (an essential on every engineer's bookshelf before the Internet), said thermal gradients were the main source of drift. These can be minimised by putting the transistors in a big heatsink, forcing the two base-emitter junctions to thermally track each other; for example, the one shown in Fig.79 and Fig.80. I have found some 'dual' transistors that consist of two dies, such as the BC847BS, are not as well matched as those made on a single die – for example, the LM364. If you want to find out what's inside, careful cracking and opening the case or even 'boiling' the case away in sulphuric acid can do it. (Incidentally, there's no point scraping numbers off chips to hide what they are to circuit prevent analysis – reverse engineers have been opening up ICs for years.) If you are a bit worried about cooking with acid (and you should be – *don't ever do it!*) there is a site full of beautiful chip images at: **zeptobars.com**. The generous photographers at this website have made their images available on a Creative Commons licence, so we can show you some of them. Fig.81 shows one of the best dual transistors made, the LM394. Fig.82 shows one of the single dies of a so-called 'dual', a BC847. Fig.83 is a 7555 timer IC.

PCB tips

To aid construction, my design only employs through-hole single-sided PCBs with tracks wide enough for home etching. These have all been produced on Autodesk Eagle, the most popular PCB CAD program within the electronic music technology community. (Incidentally, if you are new to CAD and fancy using this design tool I have found with Eagle there is plenty of online forum support, something often lacking with the expensive CAD programs.) These boards were created with the free evaluation edition, which only allows boards up to 80 x 100mm.

Autodesk Eagle has many symbol libraries, containing unusual musical components, such as the LM13600. I must confess, I'm strictly an analogue engineer who rarely ventures into the digital world – so if I can get a bit of software to work, it must be good! The only (subjective) problem is the functional artwork produced in CAD can be 'ugly'. To prove my point, the

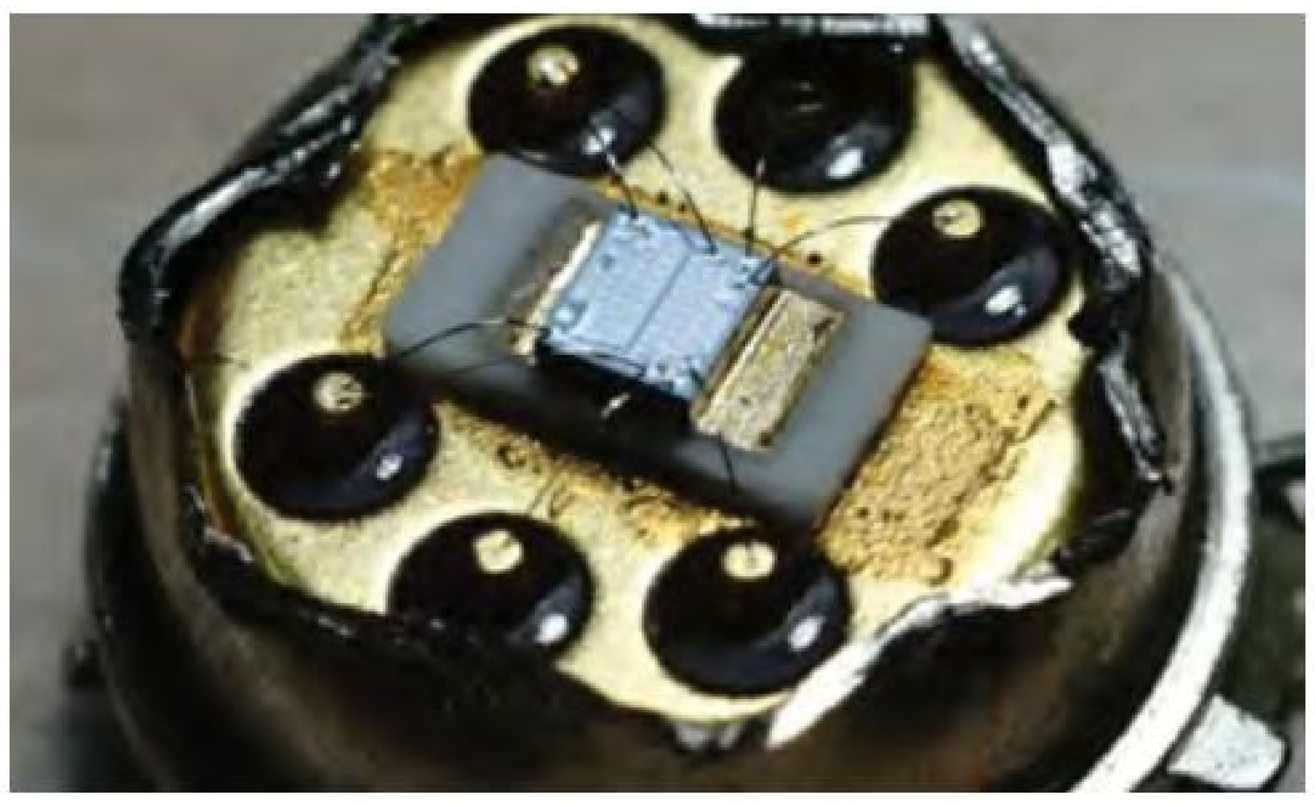

Fig.81. Photo of a dual transistor die – one of the best, National's LM394 (**zeptobars.com**)

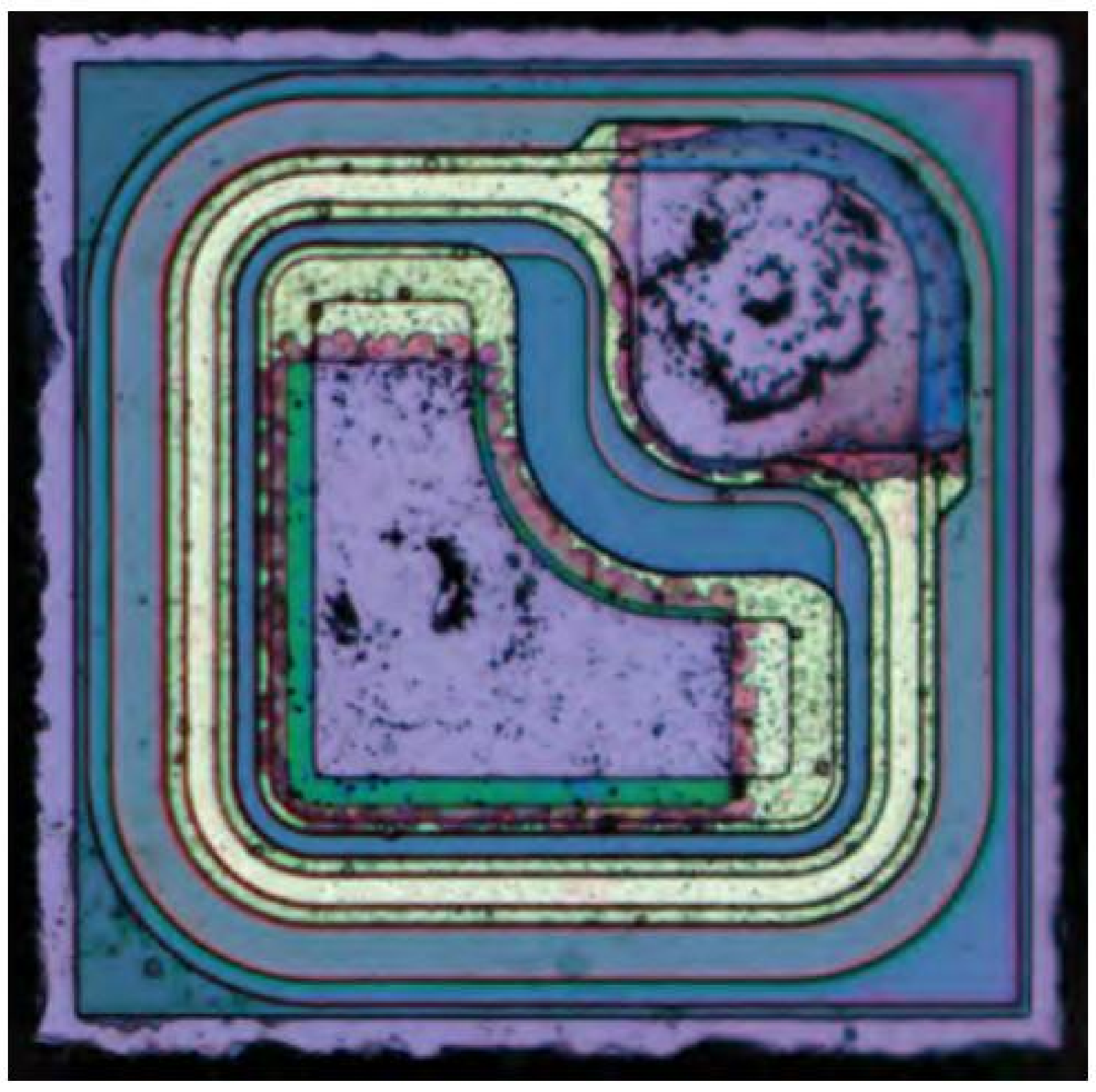

Fig.82. Die from a cheap dual transistor Philips BC847. This uses two separate dies from the same wafer. V_{be} values will be within a few per cent (**zeptobars.com**)

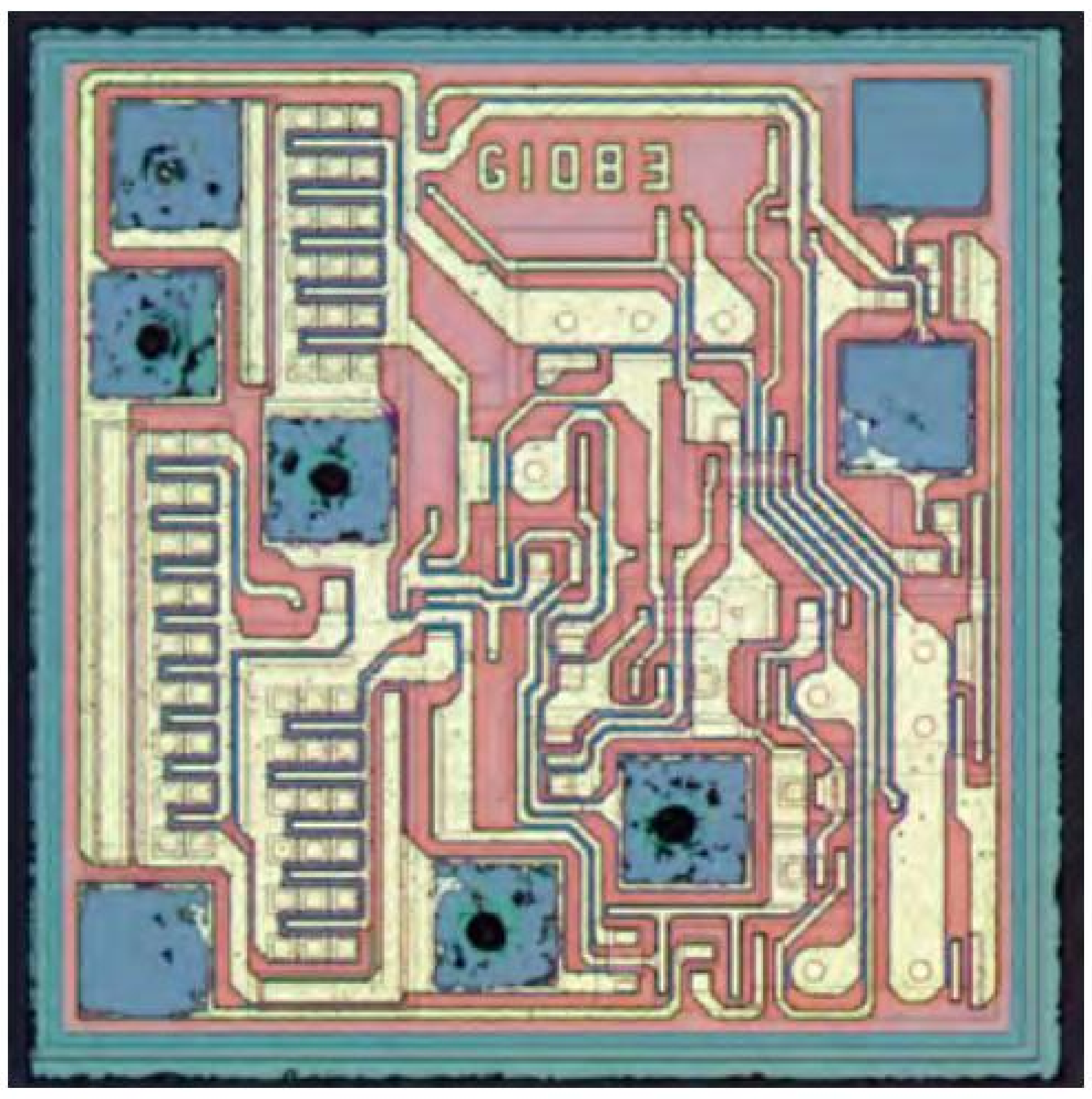

Fig.83. Just because it's beautiful, the 7555 timer IC die used in the VCO (**zeptobars.com**)

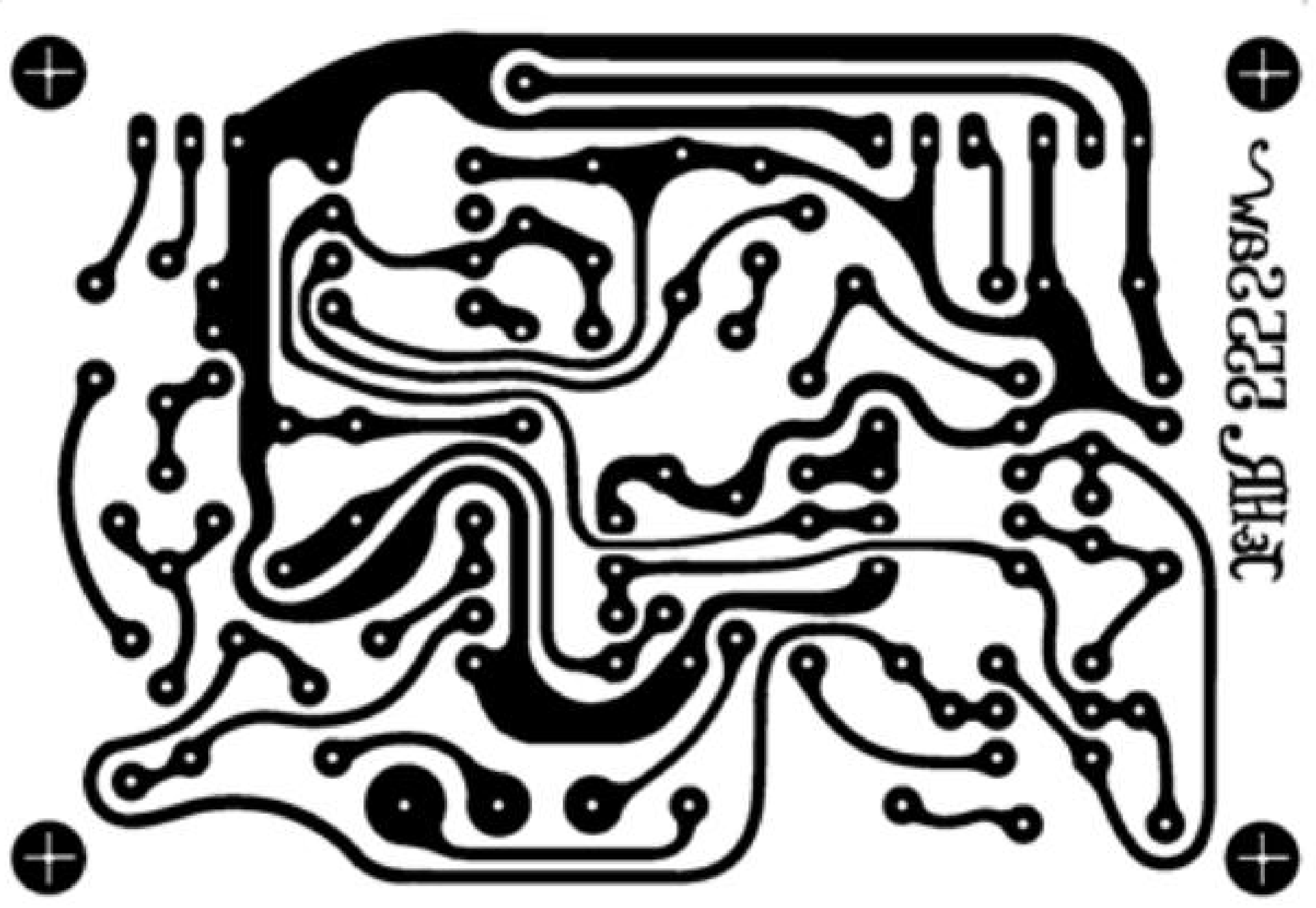

Fig.84. Even Eagle CAD boards can be made aesthetically pleasing with a bit of artistic finishing – artwork by Harvey Rothman.

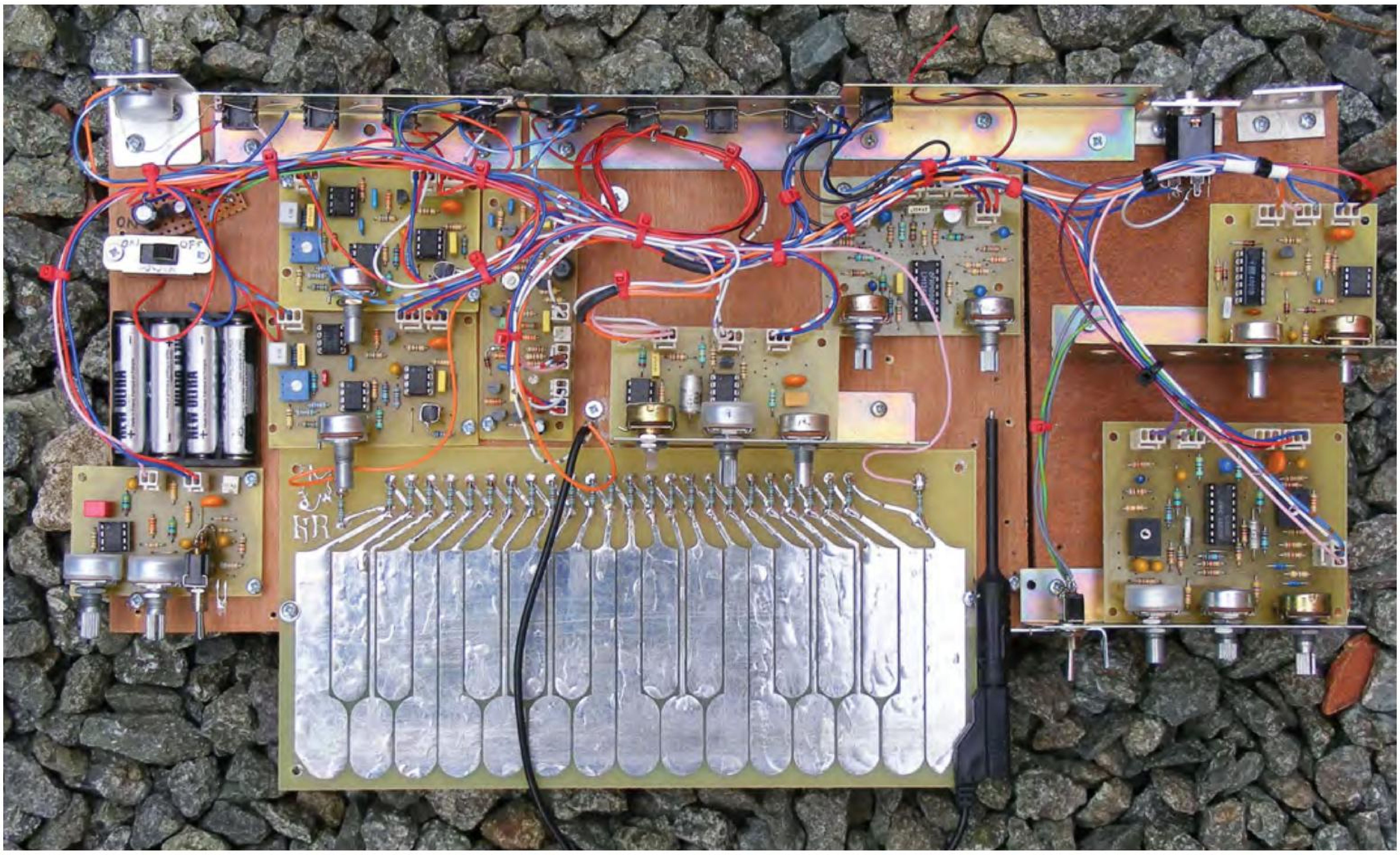

Fig.85. Look! – not a Veroboard in sight – the fully assembled PCB version of the budget analogue synthesiser.

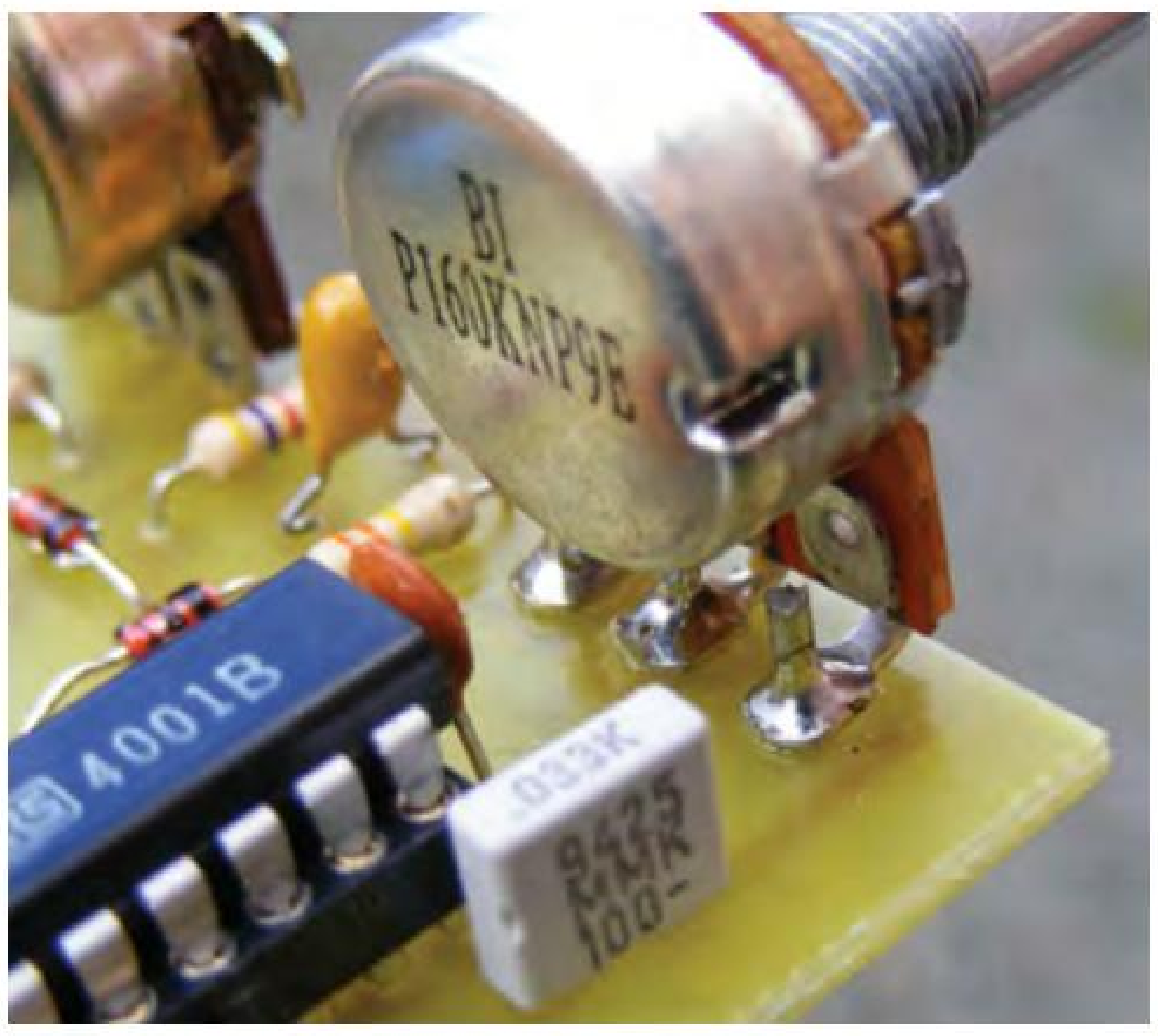
BI
P160KNP9E
4001B
.033K

Fig.86. If no PCB mount pots are available, the more robust 'tag' type can be used with 0.15 inch pitch Veropins. This arrangement protects the weak pads from detaching on single-sided boards.

Eagle artwork for the VCO board has been post-processed in Photoshop with a graphics tablet by a professional artist, see Fig.84. The result is reminiscent of Roland hand-drawn PCB designs from the 1980s. I've noticed a trend for retro PCB aesthetics to be a major selling point in guitar pedals recently. The *EPE* website will suppply these touched-up PDF artworks for traditional etching and Gerber files for those who wish to use the cheap Chinese PCB fab houses that have recently come online, such as **www.pcbway.com**. Once you build some of these modules you can pretend it's 1975 all over again, with its characteristic analogue-synth sound. It will certainly sound like that musical era when you start playing!

Construction

Fig.85 shows the synth in is present state. The Veroboard modules have now all gone, replaced by PCBs.

I would normally not use tantalum capacitors on a budget design like this. Although there are some on all the boards, they are only necessary for the decay circuits in the envelope generators. Ordinary electrolytic capacitors can be used elsewhere. (I used tantalum capacitors because I rescued a load from RoHS oblivion – in other words, I saved them from a skip.) To allow tracks to go between pins on the

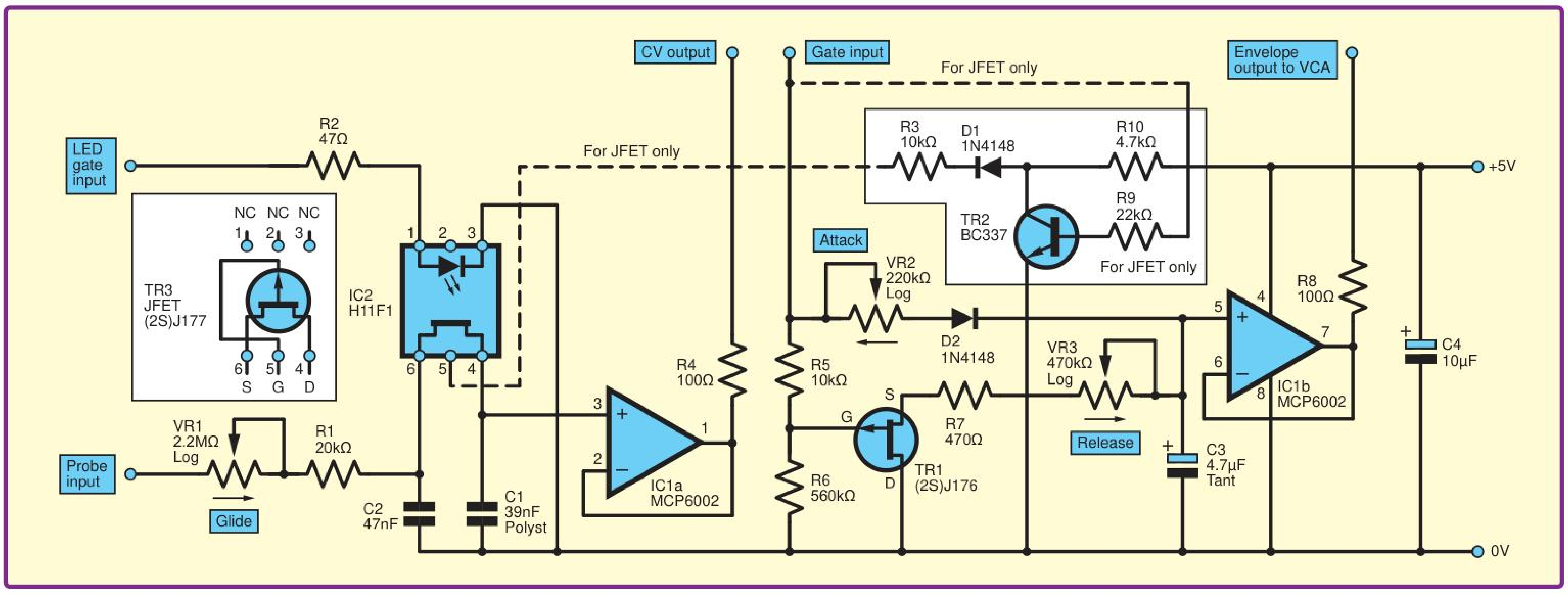
CV output
Gate input
For JFET only
Envelope output to VCA
LED gate input
R2 47Ω
For JFET only
R3 10kΩ
D1 1N4148
R10 4.7kΩ
+5V
NC NC NC
1 2 3
TR3 JFET (2S)J177
6 5 4
S G D
IC2 H11F1
1 2 3
6 5 4
TR2 BC337
R9 22kΩ
For JFET only
Attack
VR2 220kΩ Log
D2 1N4148
R8 100Ω
C4 10µF
R4 100Ω
R5 10kΩ
VR3 470kΩ Log
IC1b MCP6002
VR1 2.2MΩ Log
R1 20kΩ
Probe input
Glide
C2 47nF
C1 39nF Polyst
IC1a MCP6002
R6 560kΩ
S G D
TR1 (2S)J176
R7 470Ω
Release
C3 4.7µF Tant
0V

Fig.87. The opto-FET coupler sample and hold circuit combined with the attack/release envelope generator. Note: to save cost, the opto-FET can be omitted and replaced with a (2S)J177 and associated extra components.

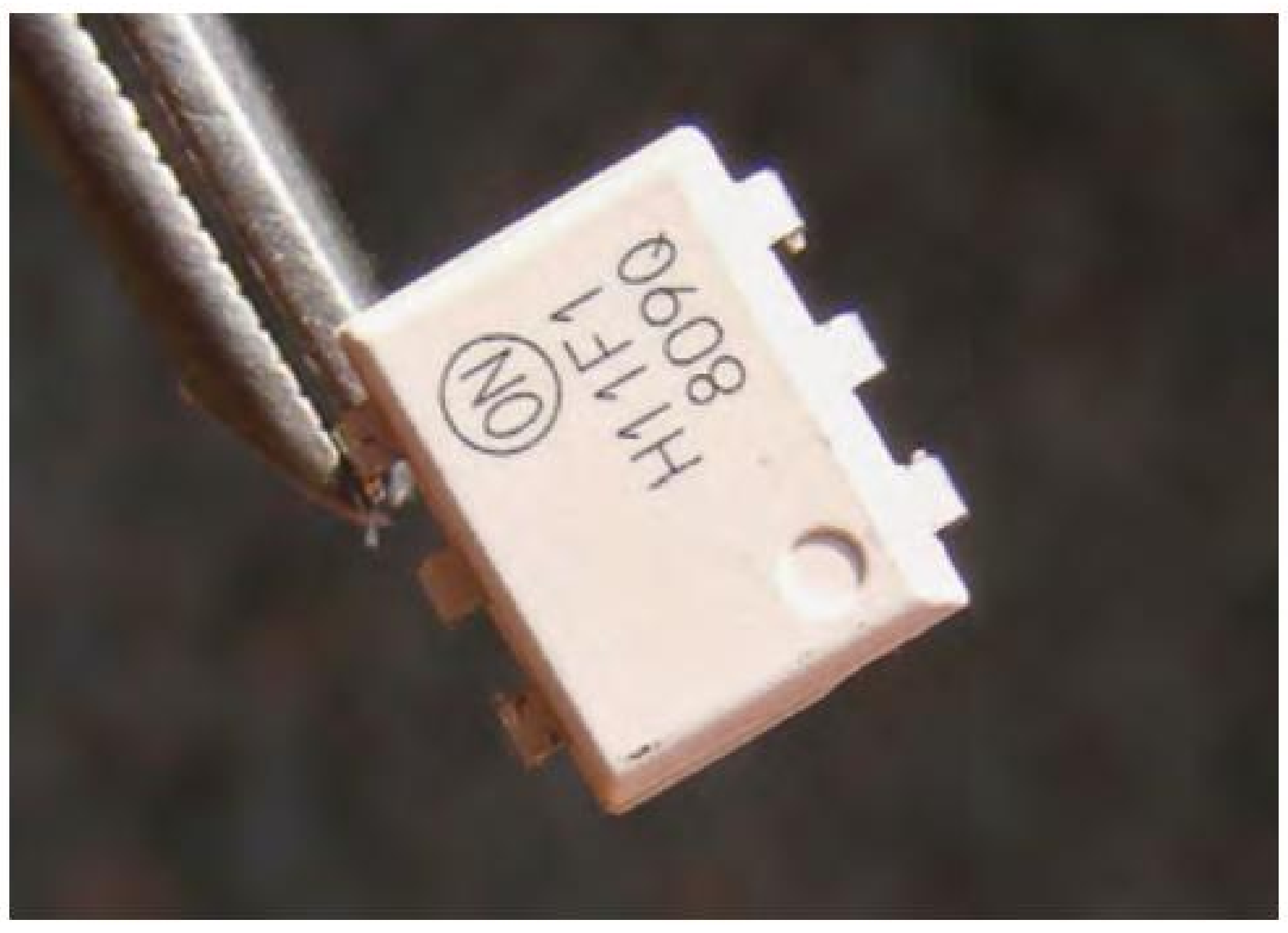
H11F1
8090
ON

Fig.88. Watch out for opto devices in white cases. Infrared light can penetrate and cause leakage currents. In a 'normal' dark enclosure this does not happen. I remember this effect occurring when black paint got chipped off germanium transistor cases.

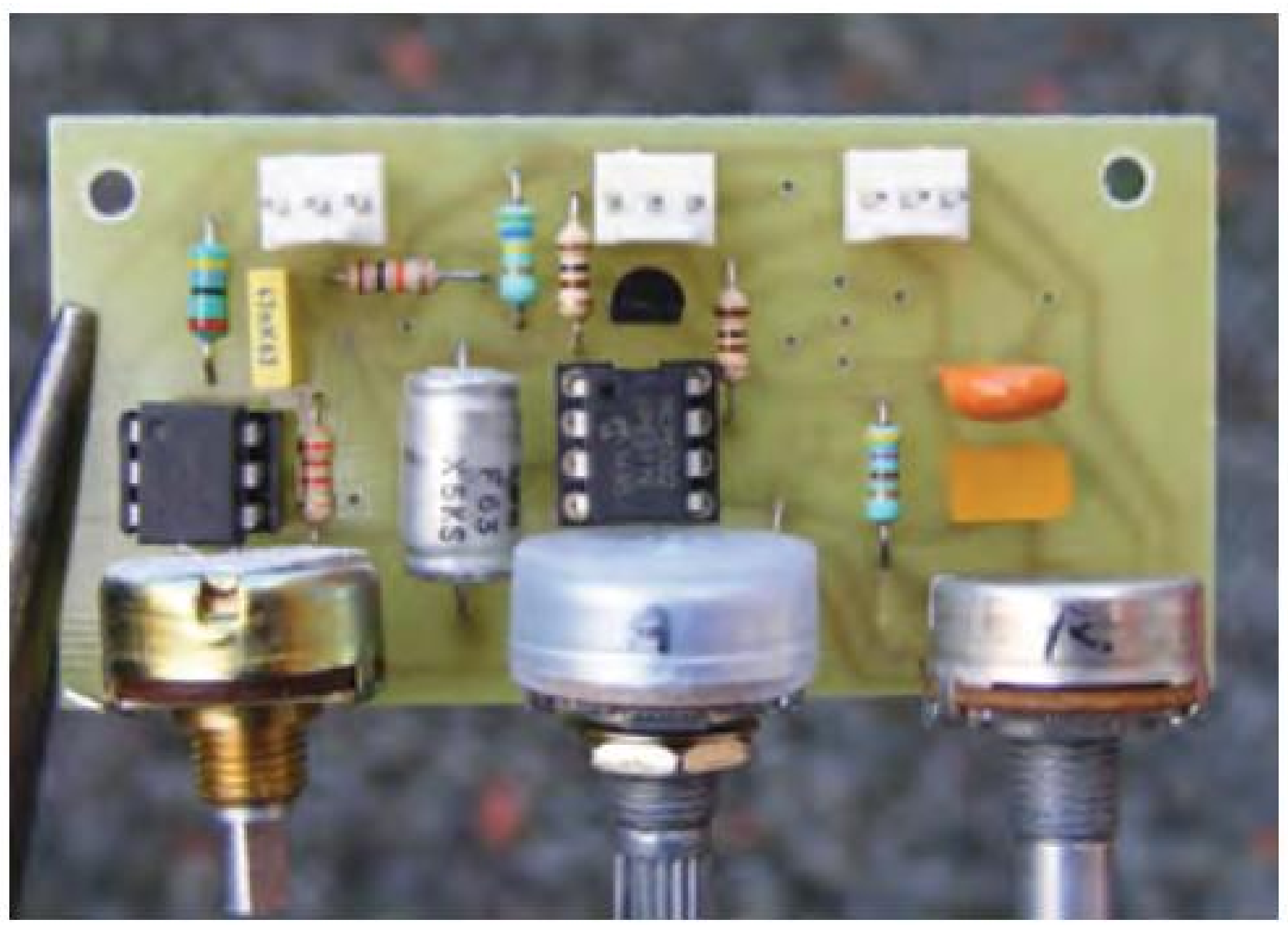

Fig.90. The completed opto-FET sample and hold AR PCB – note the spare component positions for the JFET version.

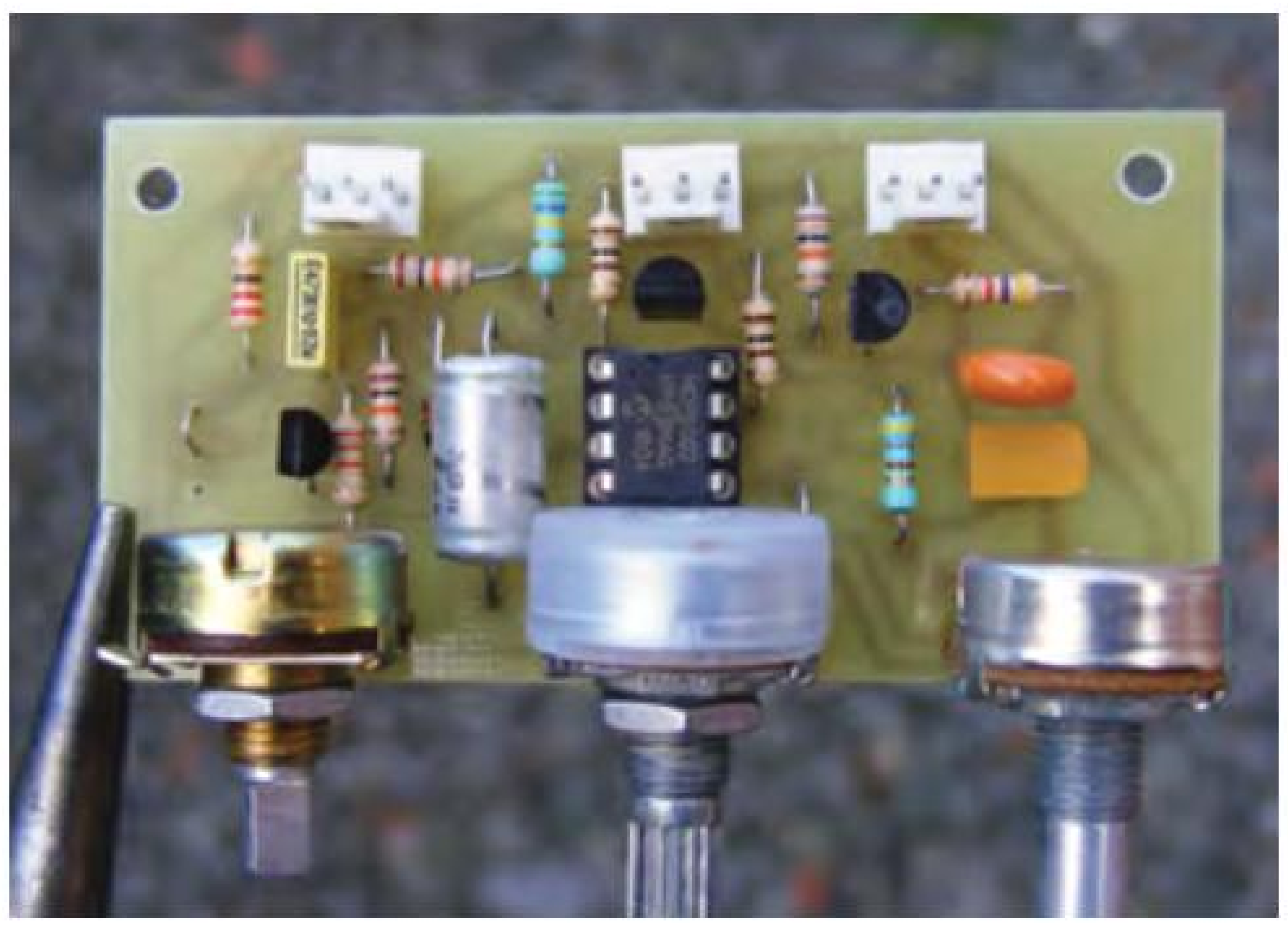

Fig.91. The completed JFET PCB – note the position of the JFET in the 6-pin DIL socket holes. It can go in either way round, since the drain and source are symmetrical. The gate pin is in the middle. An additional mod is to link the LED pins on the opto coupler holes (pins 1 and 2) and increase the series resistor to 220Ω. This keeps the gate LED illuminated on the gate PCB.

PCBs 5mm spacing has been used for most of the capacitors. This means the leads will have to be spread carefully if standard 2.5mm types are used.

Do be careful with low-cost Alpha potentiometers – these can snap off along their Paxolin base if bent too much, so ensure the board is well supported to minimise any applied leverage. Alternatively, the wired-tag version can be used instead of the PCB-mount variety. Use 0.15-inch Vero pins inserted into the PCB mounting holes, as shown in Fig.86. This arrangement is more of a fiddle to construct, but definitely much stronger.

Fussy FETs

Sample and hold circuits can be demanding when it comes to the switching element and capacitor. My circuit's design proved particularly tricky because of the low-voltage single-rail and high-frequency gate signal. This could give rise to unpredictable offsets, possibly due to rectification effects on the gate. However, an effective surface-mount JFET for the switch is the On-Semi J270 (Mouser 512-MMBF J270, cost 37p), which has a lower pinch-off voltage than the J177. The through-hole device has now become rare and expensive. The SMT version (MMBJ177) however, is still cheap at 13p each for 100 off. It should be possible to mount an SMT FET on the underside of the board if you need to.

Opto-FET sample and hold

Rather than use a JFET, which has a widely varying pinch-off voltage, a more stable and expensive solution is to use an opto-FET, such as the H11F1M made by On-Semi. This is a form of analogue opto-isolator, comprising an LED shining on an opto-FET. I found it gave more accurate note changes than with the JFET, and the accompanying inverter stage is not needed. The circuit is shown in Fig.87, although space for the JFET circuitry is provided on the board if needed. An updated attack/release circuit is also shown in Fig.87 and is included on the PCB.

Unfortunately, one opto-FET I used had a white case (see Fig.88) which occasionally suffered very bad 'droop'. The cause was leakage when a halogen desk lamp was shone on it. This effect had me confused for an hour. I felt like falling on my soldering iron. However, using this expensive device did get rid of four resistors, a JFET, a bipolar transistor and a diode, along with the associated assembly cost. The correct LED current is rather high at around 15mA. However, using an electrolytic capacitor (C11) in the keyboard controller circuit gives it a good pulse of current just as it turns on, which greatly reduces the average current. The PCB for both opto-FET and JFET versions is shown in Fig.89. The bipolar transistor has been replaced with a P-channel JFET in the A/R (attack/release) circuit. This results in a greater discharge of the capacitor with minimum release times. I used a J176 (full name 2SJ176) JFET (still cheap at Mouser, get some while you can) A J175 JFET (2SJ175) didn't work, since

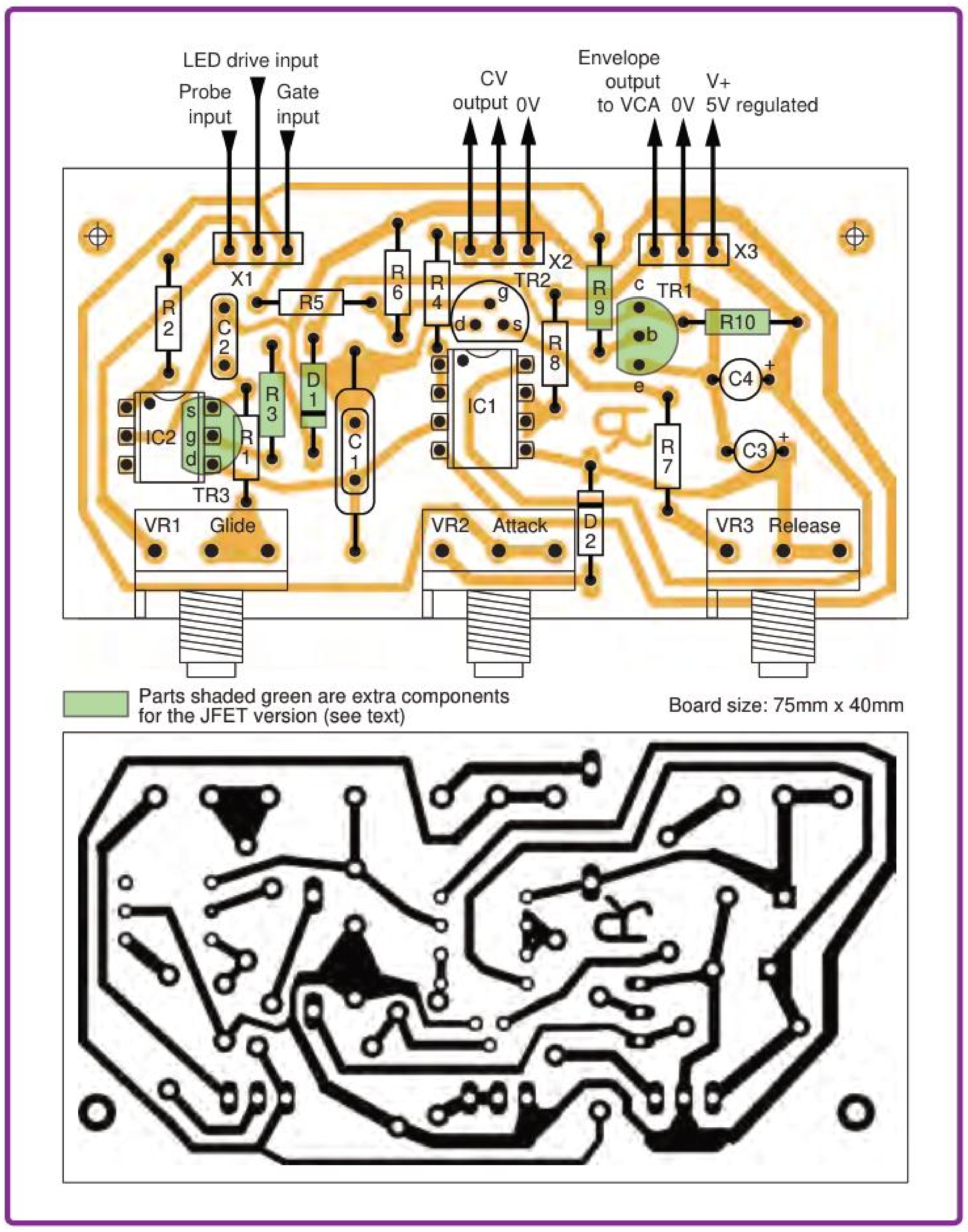
LED drive input
Probe input
Gate input
CV output
0V
Envelope output to VCA
0V
V+ 5V regulated
X1
X2
X3
R2
C2
R5
R6
R4
TR2
g
d
s
R9
c
TR1
b
e
R10
C4
C3
R8
IC1
IC2
s
g
d
R3
D1
C1
R1
TR3
R7
D2
VR1 Glide
VR2 Attack
VR3 Release
Parts shaded green are extra components for the JFET version (see text)
Board size: 75mm x 40mm

Fig.89. PCB for the sample and hold AR board. Note: components marked green are to be inserted if a JFET is used. Also note how the JFET is inserted into the right hand side of the 6-pin mounting outline of the opto-FET position. Plus, note that a surface-mount FET (J270) can be put on the track side since the middle pin is the gate on this SMT devices.

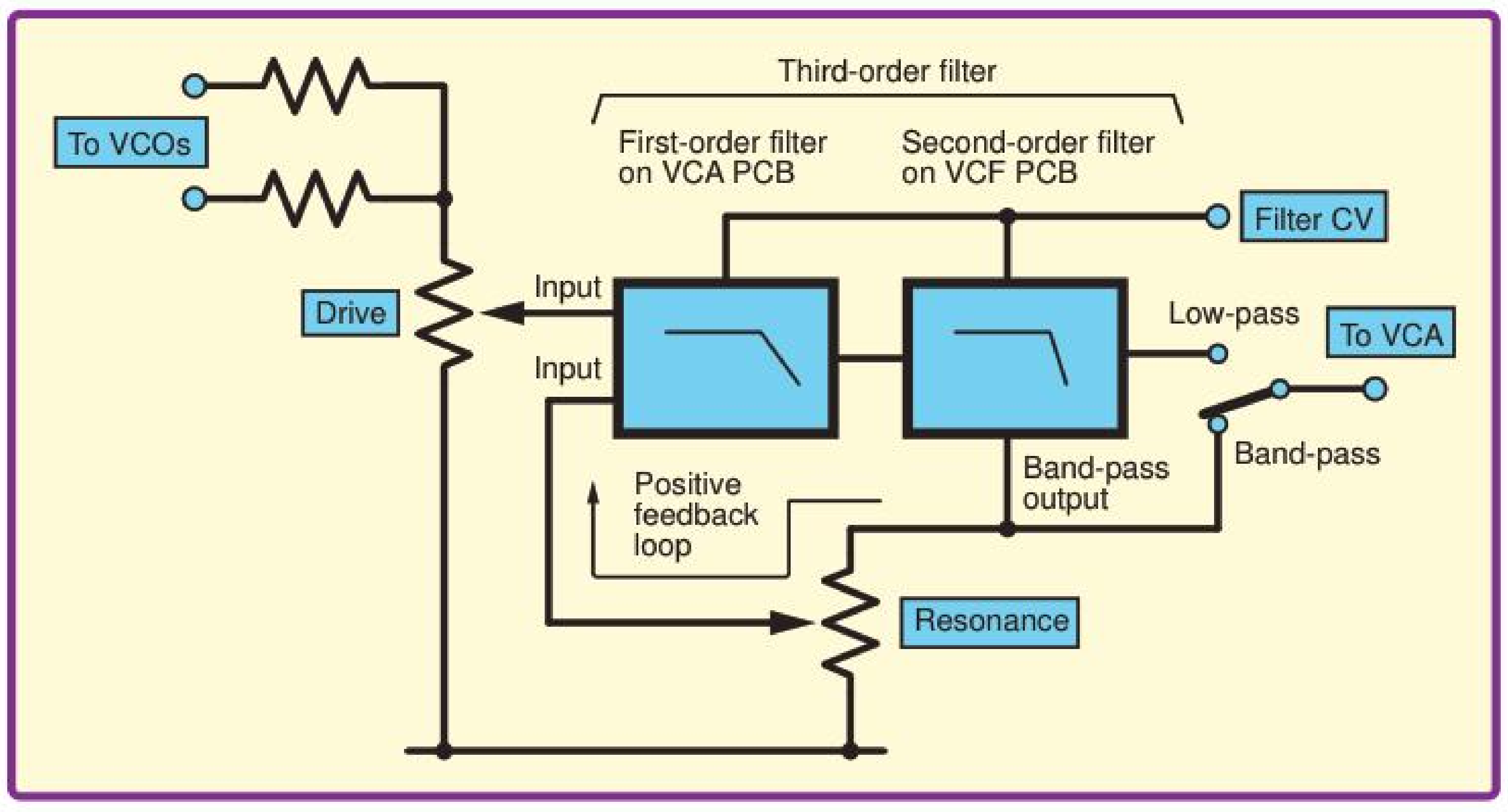
Third-order filter
First-order filter on VCA PCB
Second-order filter on VCF PCB
To VCOs
Filter CV
Drive
Input
Input
Low-pass
To VCA
Band-pass
Band-pass output
Positive feedback loop
Resonance

Fig.92. Block diagram of third-order filter arrangement spread over two PCBs to make full use of two LM13600 chips.

there was insufficient voltage to turn it fully off. Combining the two circuits provides a couple of pots to hold the PCB onto the front panel, not normally good practice, but ‘acceptable’ with small lightweight boards. This design also allows a dual op amp to be used. Figs.90 and 91 are photos of completed boards for both versions.

Parts list – Sample and Hold

Semiconductors
IC1 MCP6002
IC2 H11F1 or HF11F3 FET opto-isolator
TR1 J176 P-channel JFET, Mouser 512-J176D74Z
TR2 BC337*
TR3 (2S)J177* (or J270 SMD)
D1 1N4148*
D2 1N4148

Capacitors
C1 33nF – use low leakage and dielectric absorption polystyrene, polycarbonate or polypropylene axial or radial device. (I used 39nF because I had one and the tolerance is not critical)
C2 47nF 5mm 10% polyester
C3 4.7µF 6.3V tantalum
C4 10µF 10V electrolytic

*Resistors (*all 5% 0.25W CR25)
R1 2.2kΩ
R2 47Ω (220Ω for FET version)
R3 10kΩ*
R5 10kΩ
R4, 8 100Ω
R6 560kΩ
R7 470Ω
R9 22kΩ*
R10 4.7kΩ*

Pots
VR1 2.2MΩ log 16mm
VR2 220kΩ log 16mm
VR3 470kΩ log 16mm

Miscellaneous
3 off 3pin Molex headers Rapid 22-0955
6 pin DIL socket (not for FET version)
8 pin DIL socket

*Extra components for JFET version

VCA (voltage-controlled amplifier)

Since the LM13600 is a dual device it’s a good idea use two of them, using one section for the VCA and the remaining three sections to make a third-order filter. The block diagram of this arrangement is shown in Fig.92. Biasing of transconductance op amps is critical because they can only tolerate small signal levels. With the LM13600 Darlington buffers there is also the 1.2V voltage drop to consider. The input attenuator should be set to ensure the signal is just below clipping at full output. With the original VCA circuit in Fig.49 (*Part 2*, *EPE*, September 2018) the optimum bias is 3V. This means reducing the upper bias resistor R16 to 18kΩ. A big low-ESR bias bypass capacitor (C8) is necessary to prevent low-frequency breakthrough from the VCF to the VCA. R19 and R20 are for activating the linearising diodes for other applications, but aren’t used here.

Note that loading of the Darlington voltage followers can result in clipping of the negative half cycle. Even a load of 10kΩ will be significant, so watch out for the maximum resistance of volume control pots and other loads. If low-impedance loads have to be driven, replacing the 4.7kΩ emitter load resistor with a constant-current sink will help. A modulated-current sink will be even better. Always check for symmetrical clipping with a scope on single-rail low-voltage circuits and optimise the biasing. Twiddling with a pot on the verge of clipping with

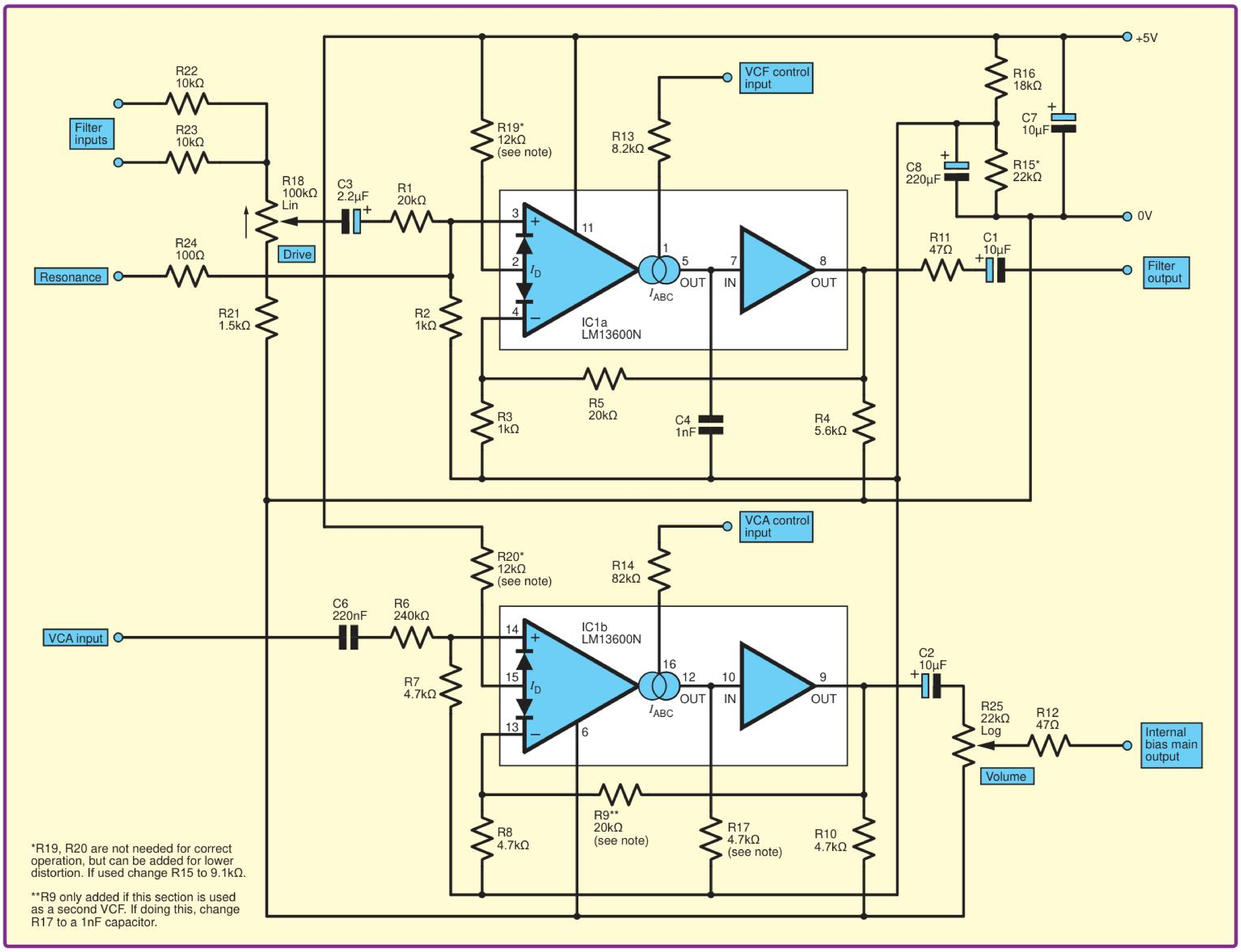
+5V
R22
10kΩ
Filter inputs
R23
10kΩ
R19*
12kΩ
(see note)
VCF control input
R13
8.2kΩ
R16
18kΩ
C7
10µF
C8
220µF
R15*
22kΩ
0V
R18
100kΩ
Lin
C3
2.2µF
R1
20kΩ
3
11
R24
100Ω
Drive
Resonance
2
I_D
1
5
7
8
OUT
IN
OUT
I_ABC
R11
47Ω
C1
10µF
Filter output
R21
1.5kΩ
R2
1kΩ
4
IC1a
LM13600N
R5
20kΩ
R3
1kΩ
C4
1nF
R4
5.6kΩ
VCA control input
R20*
12kΩ
(see note)
R14
82kΩ
C6
220nF
R6
240kΩ
VCA input
14
IC1b
LM13600N
R7
4.7kΩ
15
16
12
10
9
C2
10µF
R25
22kΩ
Log
R12
47Ω
Internal bias main output
Volume
13
6
R9**
20kΩ
(see note)
R8
4.7kΩ
R17
4.7kΩ
(see note)
R10
4.7kΩ
*R19, R20 are not needed for correct operation, but can be added for lower distortion. If used change R15 to 9.1kΩ.
**R9 only added if this section is used as a second VCF. If doing this, change R17 to a 1nF capacitor.

Fig.93. VCA circuit

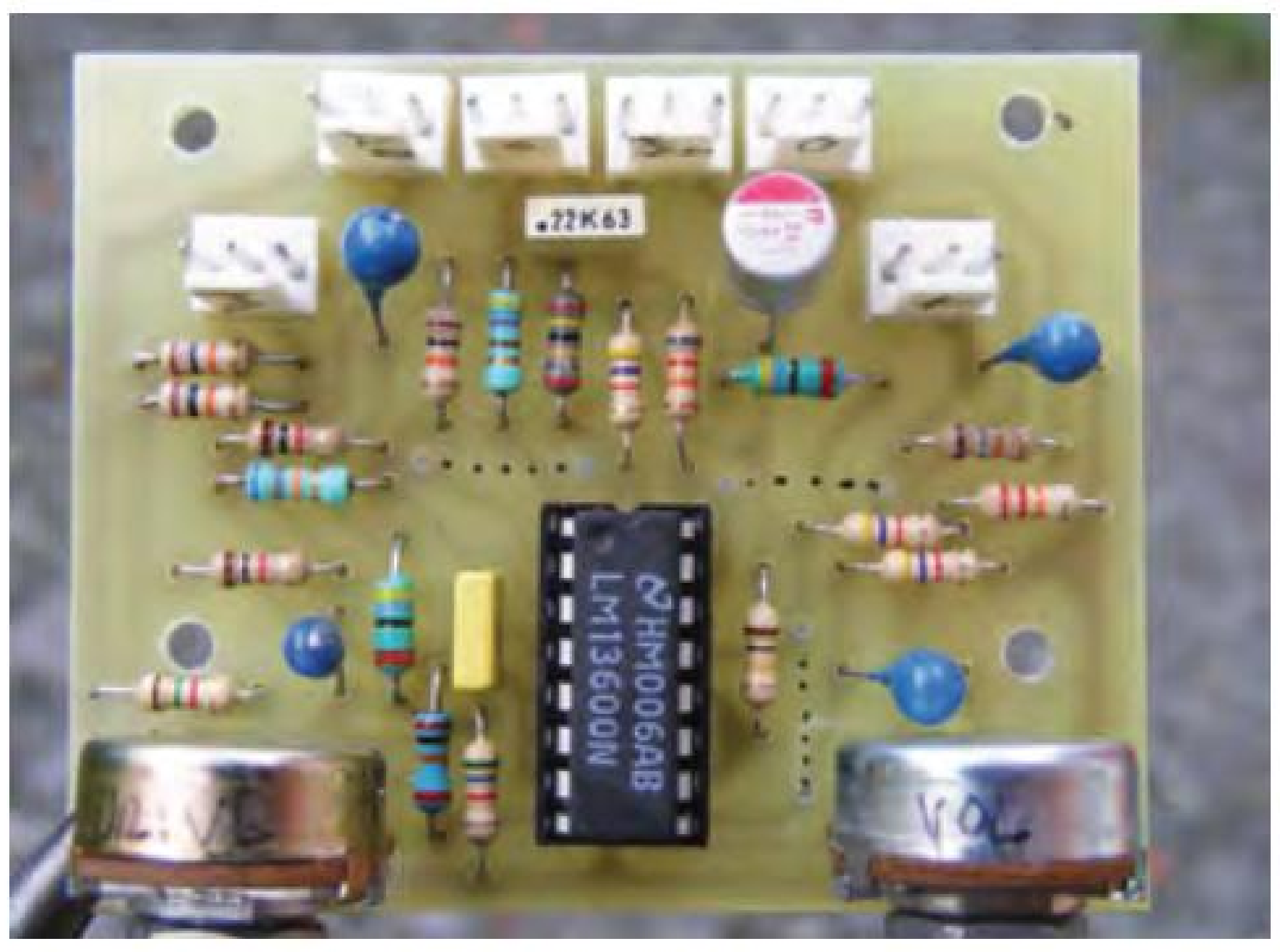

Fig.95. Completed VCA PCB.

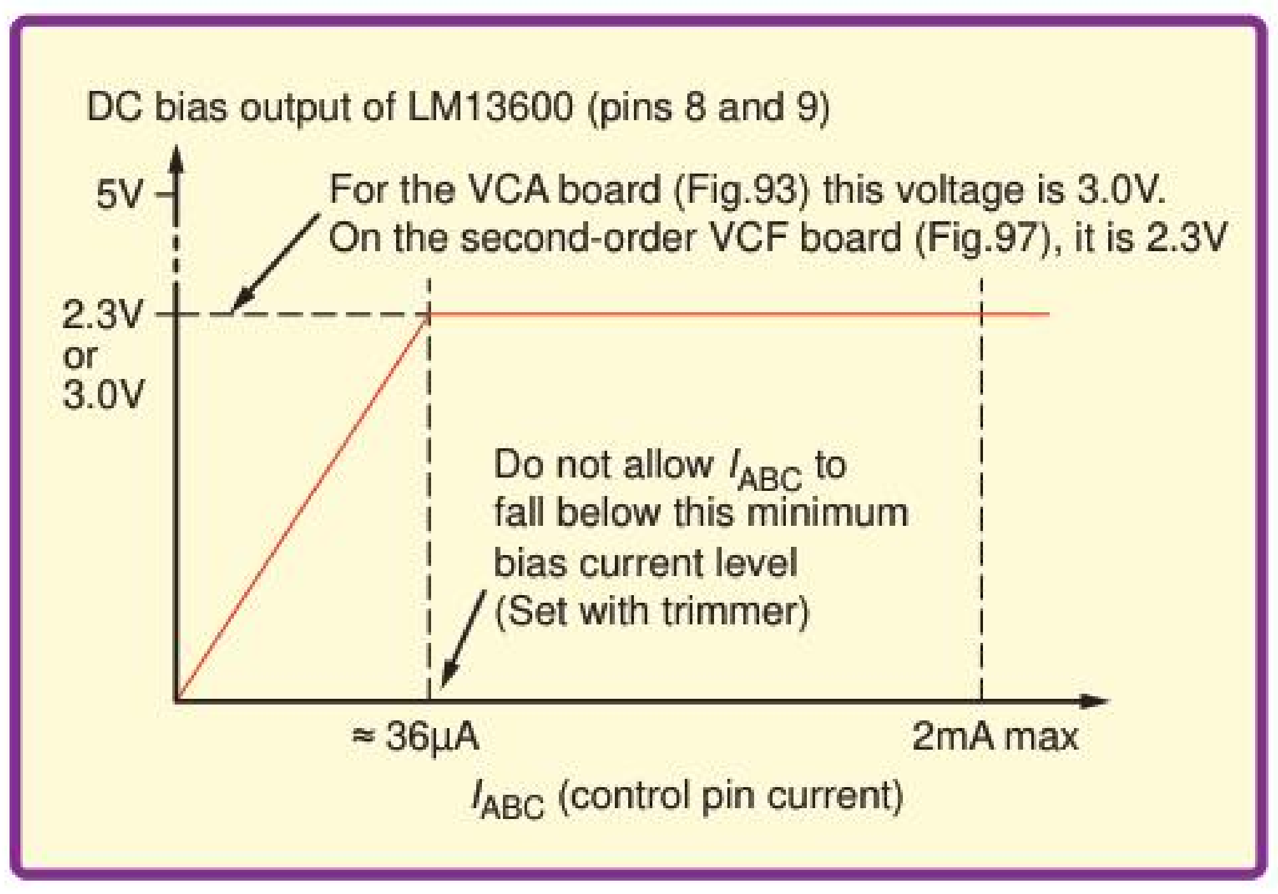

Fig.96. When using LM13600 devices on a single-rail supply, the I_{ABC} or control current should not be allowed to fall so low that the device is biased off.

an oscilloscope usually works well. With music equipment it's a good idea to listen as well – I have noticed clipping on one side (top or bottom) of the waveform sometimes sounds much worse compared to the other side.

Fig.93 shows the circuit for the VCA and the single first-order VCF section. Note that for the VCA built around IC1b the negative-feedback resistor R9 is left out. However, there is space on the board for it if a VCF section is wanted.

The PCB layout is shown in Fig.94 and the final assembly in Fig.95. This board could also be configured as a dual VCA if desired by replacing filter capacitor C4 with a 56kΩ resistor and omitting R5.

Part list – VCA board

Semiconductors
IC1 LM13600N or LM13700 16 pin DIL version

Capacitors
C1, C2, C7 10µF 10V electrolytic
C3 2.2µF 10V electrolytic
C4 1nF polystyrene or polycarbonate 5% 5mm
C6 220nF 5mm 10% polyester
C5 Not used (annotation error)
C8 220µF electrolytic

*Resistors (*all 0.25W 5% carbon film)
R1, R5 20kΩ
R2, R3 1kΩ
R4 5.6kΩ
R6 240kΩ
R7, R8, R10 4.7kΩ
R9 Not used
R11, R12 47Ω
R13 8.2kΩ
R14 82kΩ
R15 22kΩ (9.1kΩ if R19 and R20 are used)
R16 18kΩ
R17 100kΩ
R19, R20 12kΩ (optional – see text)
R21 1.5kΩ
R22, R23 10kΩ
R24 100Ω

Pots
R18 100kΩ lin 16mm Alpha
R25 22kΩ log 16mm

Miscellaneous
5 off 3-pin Molex-style 0.1-inch headers Rapid 22-0955
16-pin DIL socket

Voltage-controlled filter

The original GEN X-1 diode/transistor ladder filter was incredibly cheap, but suffered from noise. An LM13600 filter (*EPE*, May 2018) is a more consistent design, better suited for home construction. (In a production environment, its worth remembering that a single through-hole LM13600 costs more than 40 discrete SMT components.)

However, to use it here we do need some minor tweaks to the *EPE*, May 2018 circuit to make it more suitable for a synthesiser. The original linearising diodes aren't used, but they can be connected via resistors R4 and R15 if needed. The current through these diodes will change the biasing condition – see May 2018 for values. Interestingly, the optimum bias for the later filter sections was 2.3V, but the first filter section is fine with the 3V bias from the VCA.

A minimum bias current of 36µA is required through the control current pins to stop the quiescent DC output bias on the outputs suddenly dropping to zero, as shown in Fig.96. This can cause a DC thump with low modulation frequencies if the output drop to zero is allowed to happen. To avoid this thump, the LM13600 chip on the second-order filter board has a small bias preset (R34). This should be set so as to just set the DC voltage at the Darlington outputs at 2V with minimum VCF control voltage. Don't turn it too far or the filter won't fall to the required minimum. Note that there are small 470Ω resistors in series with each control pin. These provide protection – inadvertent shorts to their control pins have destroyed many a transconductance op amp. This is good safety practice if any sensitive IC pin has to be brought out to a connector on a PCB, such as on the VCA board.

Surprisingly, for such an old design, the LM13700 version of this chip is available in surface-mount LM13700MX/NOPB at around 75p from Mouser. Second-order filters are the norm for most synthesisers today, because they sound warm and acoustic. The second-order filter circuit is shown in Fig.97 and can be used on

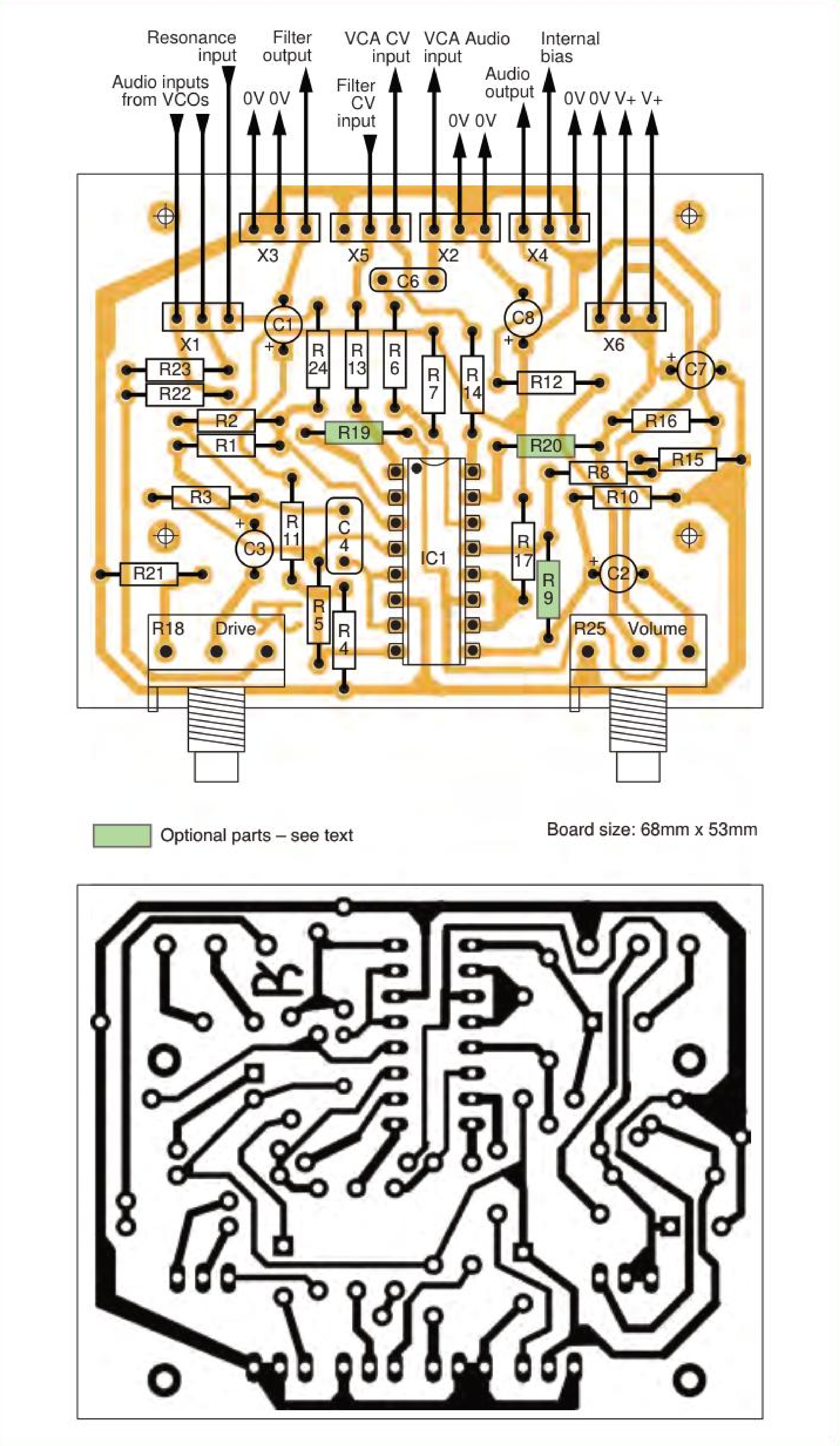

Fig.94. PCB layout for the VCA.

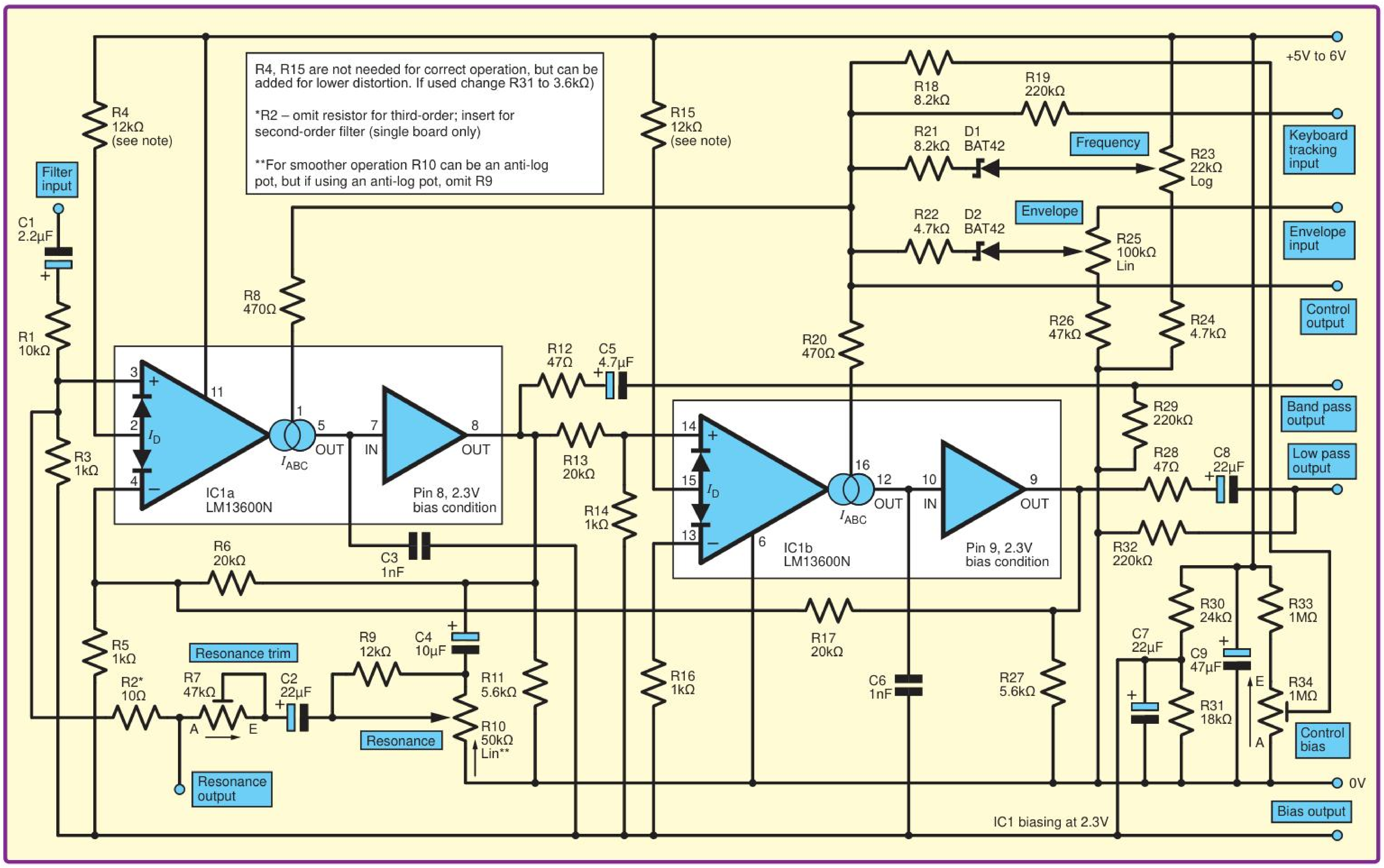
R4, R15 are not needed for correct operation, but can be added for lower distortion. If used change R31 to 3.6kΩ)
*R2 – omit resistor for third-order; insert for second-order filter (single board only)
**For smoother operation R10 can be an anti-log pot, but if using an anti-log pot, omit R9
+5V to 6V
Filter input
C1 2.2µF
R1 10kΩ
R3 1kΩ
R4 12kΩ (see note)
R8 470Ω
IC1a LM13600N
I_D
I_ABC
OUT
IN
OUT
Pin 8, 2.3V bias condition
R6 20kΩ
C3 1nF
R5 1kΩ
Resonance trim
R2* 10Ω
R7 47kΩ
A
E
C2 22µF
R9 12kΩ
C4 10µF
R11 5.6kΩ
R10 50kΩ Lin**
Resonance
Resonance output
R12 47Ω
C5 4.7µF
R13 20kΩ
R14 1kΩ
R15 12kΩ (see note)
R16 1kΩ
IC1b LM13600N
Pin 9, 2.3V bias condition
R17 20kΩ
C6 1nF
R27 5.6kΩ
R20 470Ω
R18 8.2kΩ
R19 220kΩ
R21 8.2kΩ
D1 BAT42
Frequency
R23 22kΩ Log
Keyboard tracking input
R22 4.7kΩ
D2 BAT42
Envelope
R25 100kΩ Lin
Envelope input
R26 47kΩ
R24 4.7kΩ
Control output
R29 220kΩ
Band pass output
R28 47Ω
C8 22µF
Low pass output
R32 220kΩ
R30 24kΩ
R33 1MΩ
C7 22µF
C9 47µF
R31 18kΩ
R34 1MΩ
Control bias
0V
Bias output
IC1 biasing at 2.3V

Fig.97. The second-order voltage-controlled filter circuit. The resonance feedback can be fed into the first stage here, or into the other filter stage in the third-order system.

its own (with R2 inserted) or cascaded with another first or second-order section. The PCB layout is shown in Fig.98 and the assembled board in Fig.99. I prefer the wet squelchy sound of the third- and fourth-orders designs. The effect can be humorous and is ideal for animation Foley. The two boards are wired together, as shown in Fig.100.

Summing voltages

There are a lot of control voltages to be combined for the VCF. The normal way is to use a virtual-earth summing amplifier to avoid interactions between the control pots. These inverting amplifiers can cause problems in a single-rail system, upsetting biasing if the signal needs to go below zero. In this circuit, simple resistive mixing is used with blocking diodes (D1 and D2) to prevent pot interaction. These have a forward voltage drop, which can be overcome with a little voltage bias. Using Schottky diodes minimises the drop. The audio mixing is easily accomplished at the input attenuator, and the 200Ω lower arm of the potential divider prevents significant interaction.

Resonance and knob twiddling

The filter can be made to self-oscillate by adjusting feedback preset R7 until it just oscillates, with the resonance pot turned fully up. It is possible to place the filter after the VCA because it's a useful sinewave source in itself and the overall decay sweep sounds better. However, it is also possible to cause excruciating feedback and blow up tweeters with ham-fisted operation. Remember – the Hippocratic Oath of audio is (or certainly should be) 'thou shall not deafen thy audience'. On balance, I think it's best to play it safe and put the VCA last. An anti-log pot is best for the resonance control since the danger region at the clockwise end is spread out and less abrupt. In this case, a linear pot is used with a loading resistor R9 to bend its law.

One of the great things about analogue synthesisers is that the range of control can be made to run from extreme to sublime subtlety using the instant adjustments that only potentiometers can provide. The resonance control is a positive feedback loop around the filter sections. It does not work so well when encompassing all sections of a fourth-order filter, possibly because the phase shift is excessive.

With analogue systems one can spend hours optimising the gain structure. The sensible approach is to not allow the VCF and VCA to clip in normal operation with the resonance up, although many musicians might disagree. This is why there is a drive level pot (VR1) on the VCF input to provide distortion when desired.

Wobbly bits

A little bit of modulation of the filter frequency from the main signal seems to be a defect that gives character to the ladder type filters. With this filter it can be added by bleeding a bit of the oscillator output into the control voltage port with a 2MΩ pot. In this case, overdriving the filter just to clipping gives an interesting modulation effect. Although I've moaned about interactions causing havoc in electronics, controlled linkages between sections in analogue synthesisers does help produce 'acoustical' sounds. This happens in acoustic instruments, with their multiple coupled resonances between strings and wooden components. Sample and hold glitches are an identifying characteristic of analogue synths. With their digital and sample-based counterparts, the waveform starts at the same point every time a note is played, a sonic signature of digital synthesis.

Filter tracking

Filter tracking is a feature built into most analogue synthesisers, including this one. It's where the filter frequency tracks or at least travels with the note frequency. This does not have to be accurate octave for octave. An arbitrary amount dialled in with a 500kΩ pot from the output of the sample and hold is good enough. I left mine fixed with a 220kΩ resistor (R19). However, if it is desired to use the filter as an oscillator

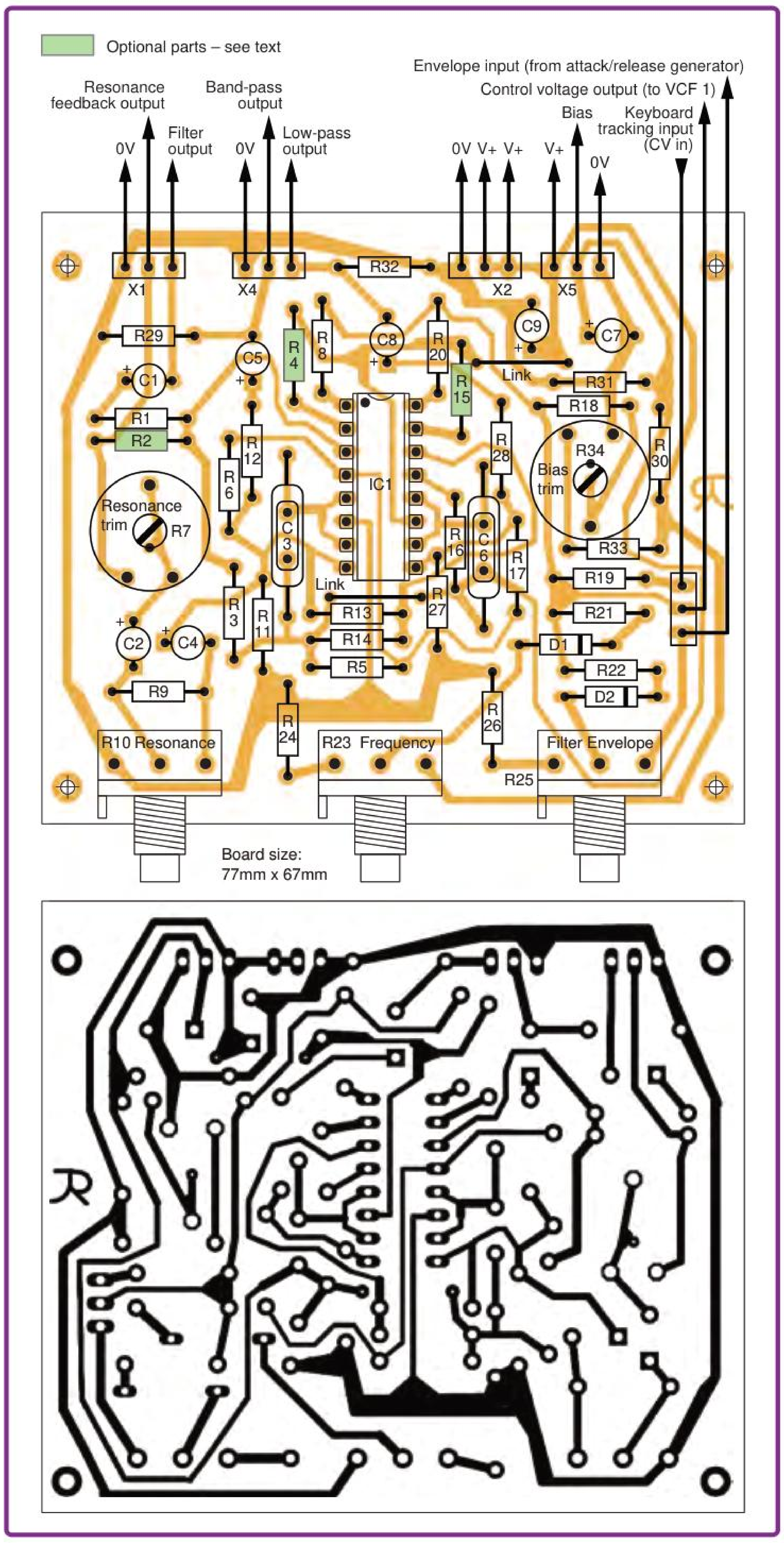
🟩 Optional parts – see text
Resonance feedback output
Band-pass output
0V
Filter output
0V
Low-pass output
Envelope input (from attack/release generator)
Control voltage output (to VCF 1)
Bias
Keyboard tracking input (CV in)
0V V+ V+
V+
0V
X1
X4
R32
X2
X5
R29
C5
R4
R8
C8
R20
C9
C7
C1
R15
Link
R31
R18
R1
R2
R12
R6
R28
R34
Bias trim
R30
Resonance trim
R7
C3
IC1
C6
R16
R17
R33
Link
R19
R3
R11
R27
R13
R21
R14
D1
C2
C4
R5
R22
R9
R24
R26
D2
R10 Resonance
R23 Frequency
Filter Envelope
R25
Board size: 77mm x 67mm

Fig.98. Second-order VCF PCB – don't forget the two wire links.

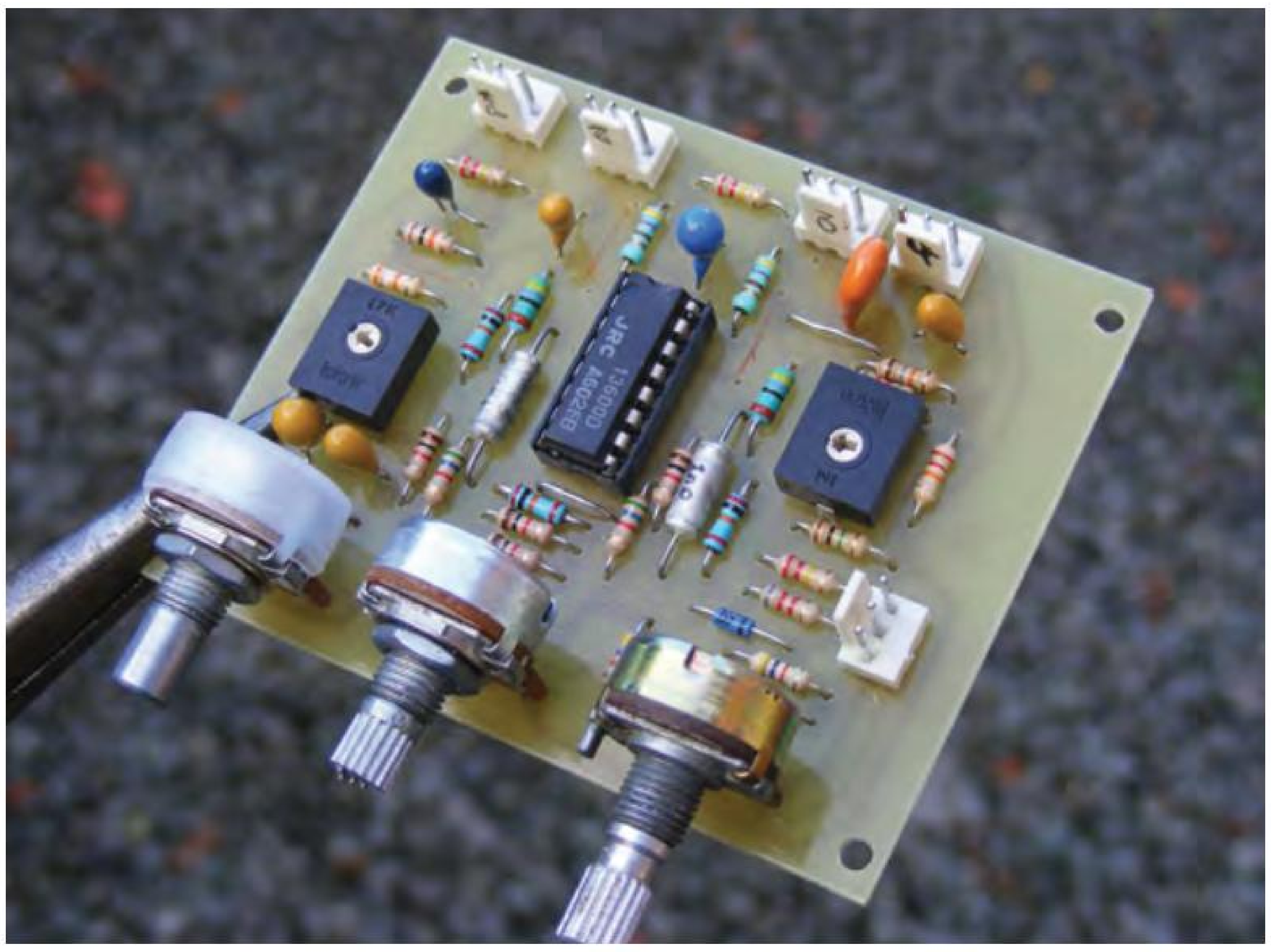

Fig.99. Second-order VCF PCB completed.

with accurate notes, it is necessary to build a virtually new filter as a VCO with an exponentiator.

Parts list – VCF

Semiconductors
IC1 LM13600/700
D1, D2 BAT42 or BAT86 schottky diode

Capacitors
C1 2.2µF electrolytic
C2 22µF electrolytic
C3, C6 1nF 5%, 10mm axial or 5mm radial – use polystyrene, polypropylene or polycarbonate
C5 4.7µF electrolytic
C7, C8 22µF electrolytic
C9 47µF electrolytic

Resistors
R1 10kΩ
R2 Not used (100Ω for second-order filter only)
R3, R5, R14, R16 1kΩ
R4, R15 12kΩ (Optional – see text)
R6, R13, R17 20kΩ
R7, R20 470Ω
R9 12kΩ
R11, R27 5.6kΩ
R12, R28 47Ω
R18, R21 8.2kΩ
R19, R29, R32 220kΩ
R22, R24 4.7kΩ
R26 47kΩ
R30 24kΩ
R31 18kΩ (3.6kΩ if R4 and R15 are used)
R33 1MΩ

Pots and trimmers
R7 47kΩ trimmer
R34 1MΩ trimmer
R10 50kΩ lin 16mm vertical pot
R25 100kΩ lin 16mm vertical pot
R23 22kΩ log 16mm vertical pot

Miscellaneous
5 off 3-pin Molex style headers
16-pin DIL socket
26 SWG wire for links

Filter attack/decay (AD) envelope generator

I was going to do a full ADSR (attack/decay sustain/release) circuit to control both filter and VCA, but that will have to wait – there is only so much that can be crammed into an introduction! I found it more expressive to have two separate simpler envelope generators (costing the same in total) for the filter and VCA. The filter envelope generator is different in that it is an AD design rather than the AR (attack/release) circuit used for the VCA. This allows the filter sweeping to keep moving over the playing of the whole note. Any analogue synthesiser worthy of the name must be able to do the 'waahh' sound.

An AD envelope generator is surprisingly more complex than the AR. First, a trigger pulse has to be generated when the gate signal starts. This is done with a couple of RC networks and a flip-flop built around a total of four gates. I used a CD4001 quad NOR because I have tubes of them. The Gen X-1 used an SMT 74HC02. In that design the usual attack and decay pots control the charge/discharge of a capacitor via steering diodes. An emitter follower based around TR1 gives enough current for a fast attack,

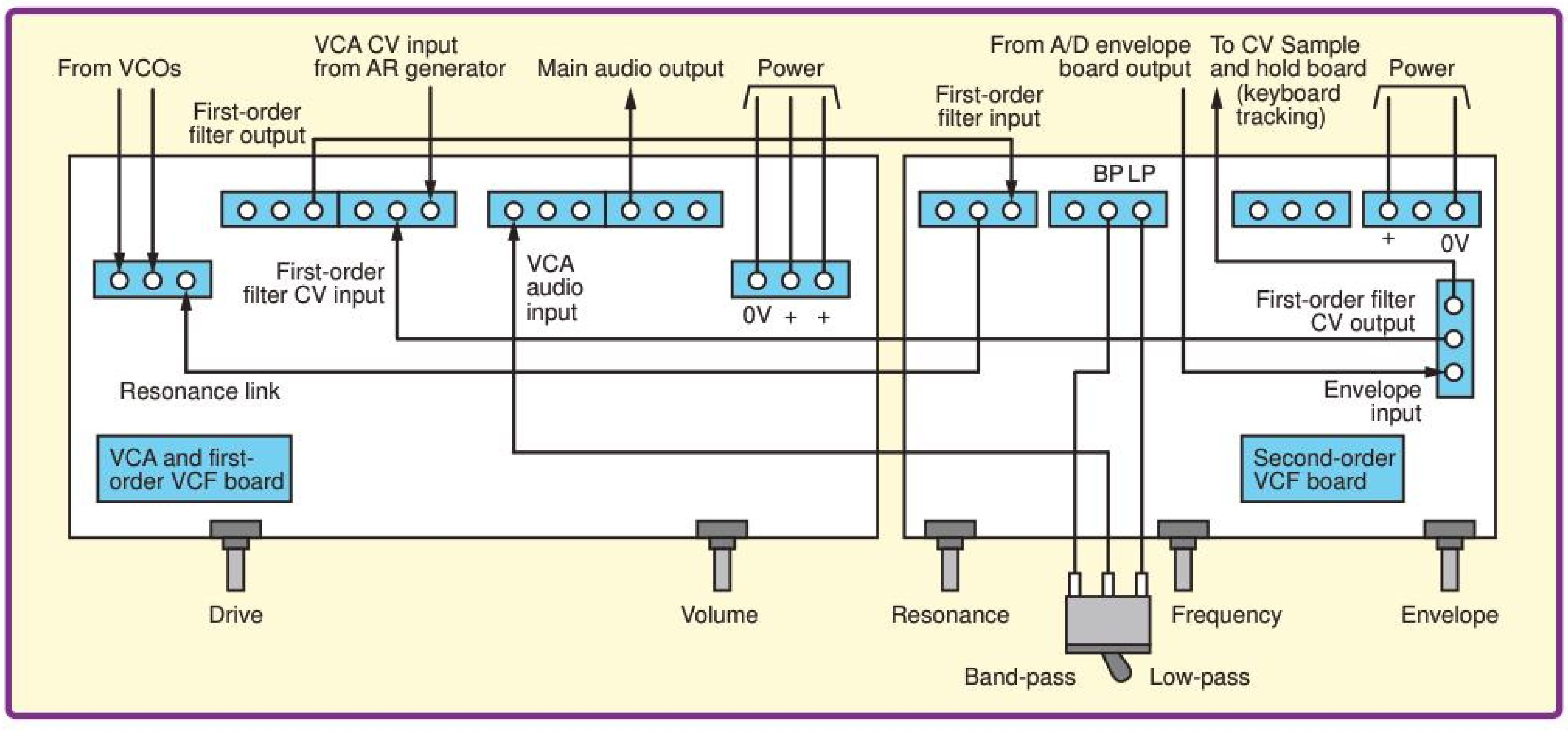
From VCOs
VCA CV input from AR generator
Main audio output
Power
First-order filter output
First-order filter CV input
VCA audio input
0V + +
Resonance link
VCA and first-order VCF board
From A/D envelope board output
To CV Sample and hold board (keyboard tracking)
Power
First-order filter input
BP LP
+ 0V
First-order filter CV output
Envelope input
Second-order VCF board
Drive
Volume
Resonance
Frequency
Envelope
Band-pass
Low-pass

Fig.100. This is how the two boards – VCF and VCA – are wired together.

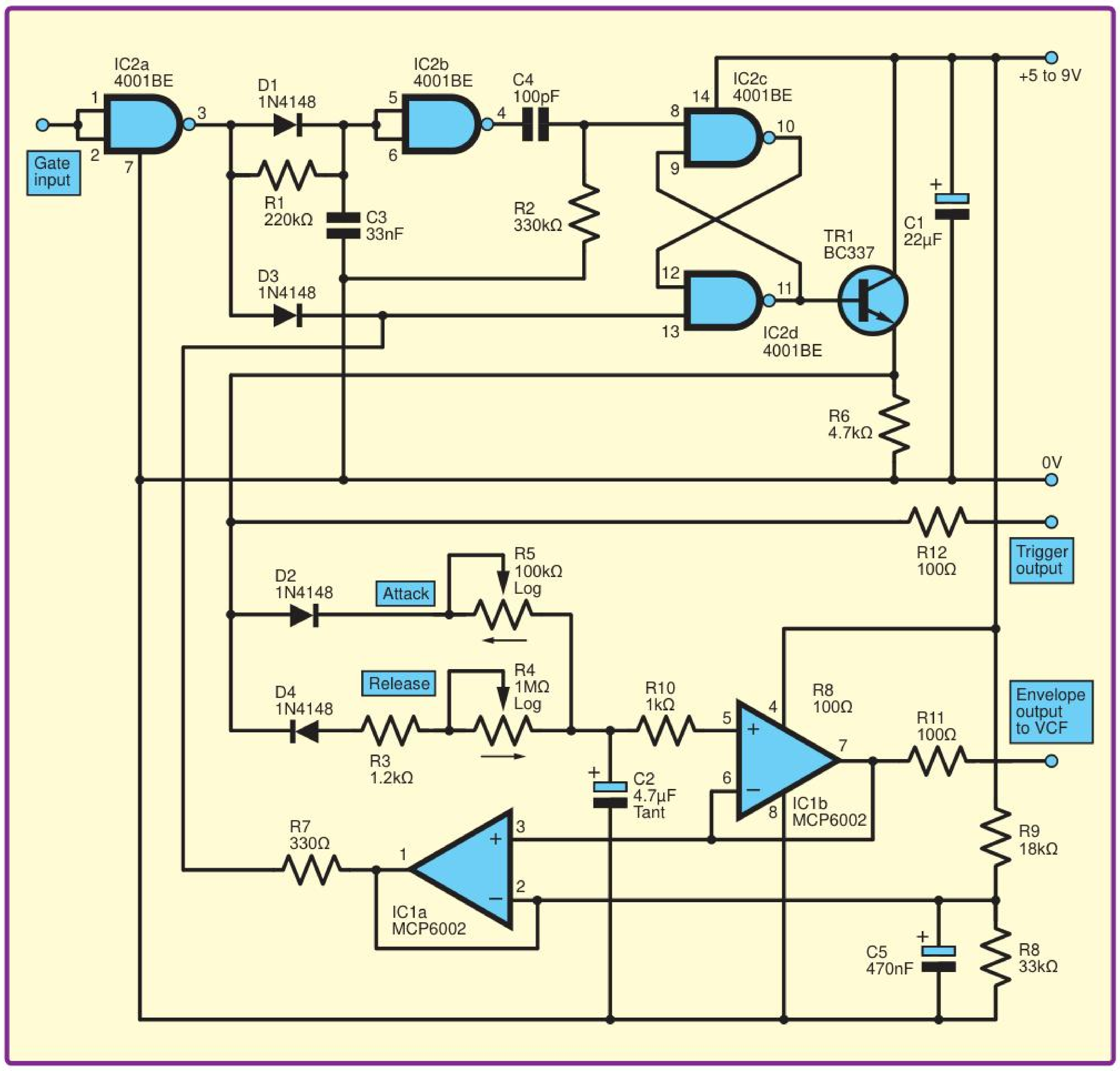
IC2a
4001BE
Gate input
1
2
3
7
D1
1N4148
IC2b
4001BE
5
6
4
C4
100pF
IC2c
4001BE
14
8
10
9
+5 to 9V
R1
220kΩ
C3
33nF
R2
330kΩ
TR1
BC337
C1
22µF
D3
1N4148
12
11
13
IC2d
4001BE
R6
4.7kΩ
0V
R12
100Ω
Trigger output
D2
1N4148
Attack
R5
100kΩ
Log
Release
R4
1MΩ
Log
D4
1N4148
R3
1.2kΩ
R10
1kΩ
C2
4.7µF
Tant
R8
100Ω
IC1b
MCP6002
R11
100Ω
Envelope output to VCF
R7
330Ω
IC1a
MCP6002
R9
18kΩ
C5
470nF
R8
33kΩ

Fig.101. The attack/decay (AD) circuit.

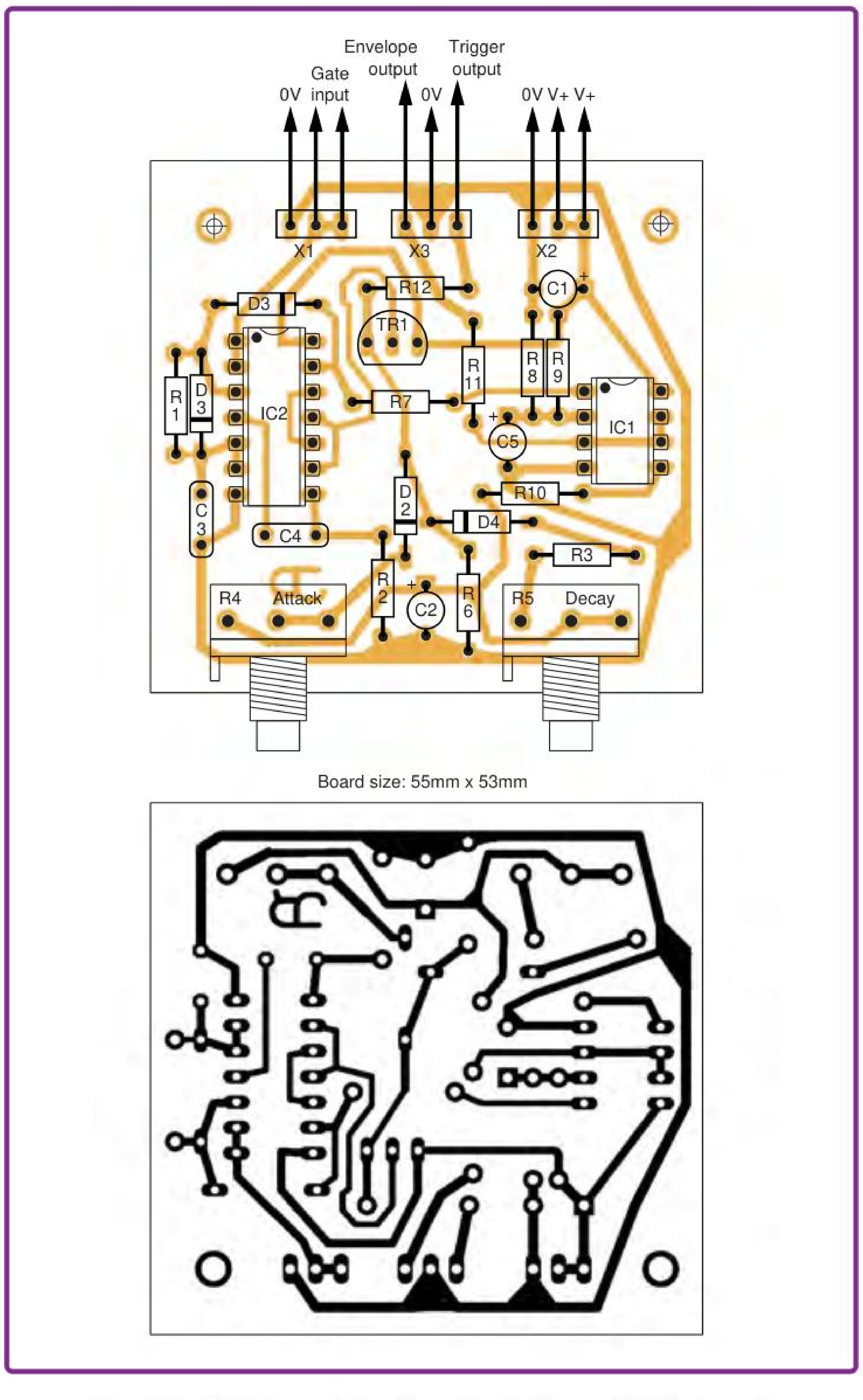
Envelope output
Trigger output
Gate input
0V
input
0V
0V V+ V+
X1
X3
X2
R12
C1
D3
TR1
R 1
D 3
IC2
R 11
R 8
R 9
R7
IC1
C5
D 2
R10
D4
C 3
C4
R3
R4
Attack
R 2
C2
R 6
R5
Decay
Board size: 55mm x 53mm

Fig.102. PCB layout for the attack/decay (AD) circuit.

which the CMOS gate alone couldn't provide. This capacitor is then buffered by IC1a. Finally, the flip-flop has to be reset after the attack/decay cycle is complete. Comparator IC1b generates a reset pulse when the output voltage drops back down to zero.

The complete attack/delay (AD) circuit is shown in Fig.101. Some envelope generators take the comparator pulse and put it back into the gate input to make an extra LFO. This circuit does not have enough gain to do that, an experiment for later. The trigger pulse can be mixed with the audio to give a click effect, ideal for percussive bass sounds. The AD PCB is given in Fig.102 and a picture of the completed module in Fig.103.

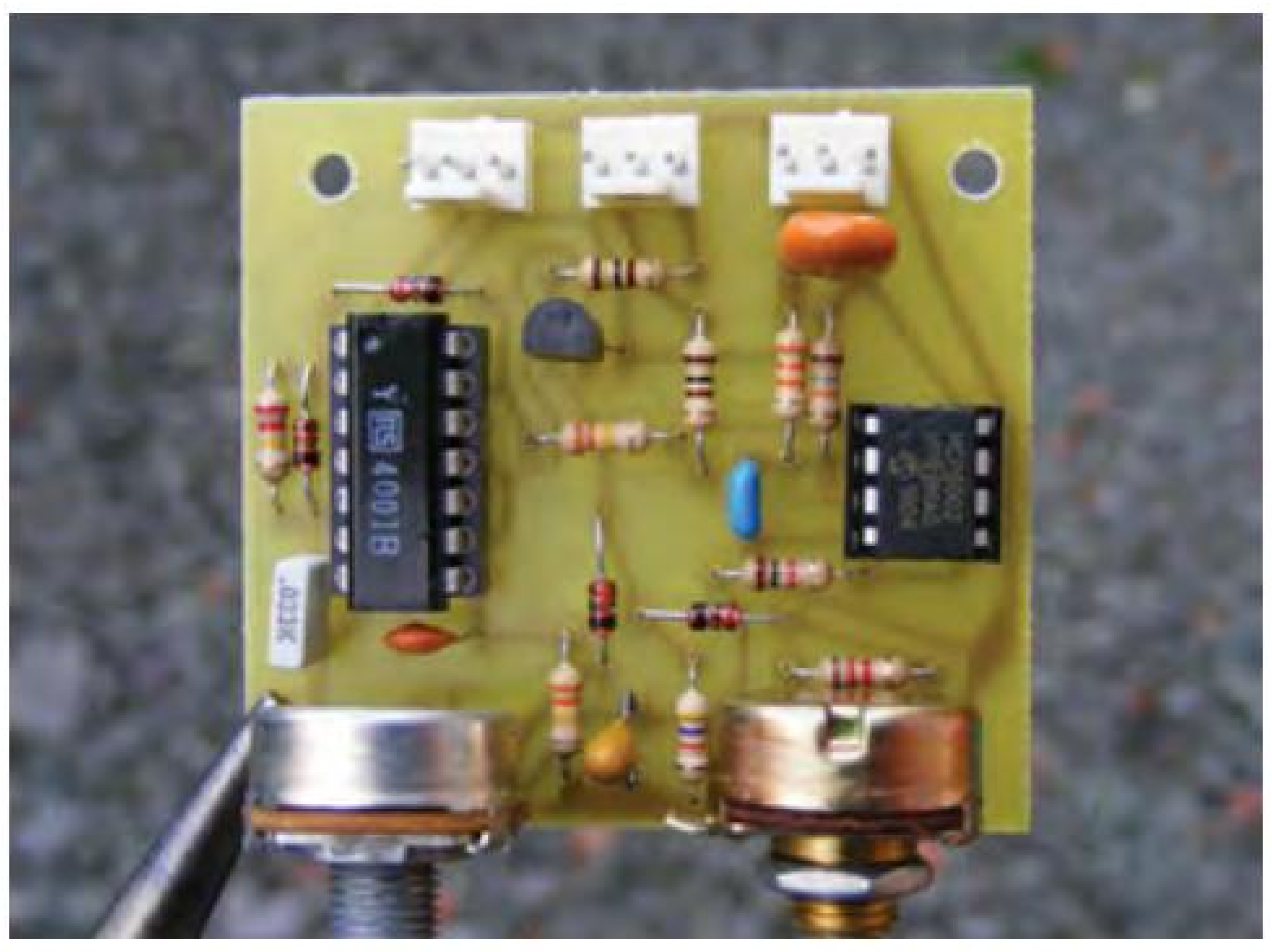

Fig.103. Completed attack/decay (AD) PCB.

Parts List – Filter AD envelope generator

Semiconductors
IC1 4001B CMOS quad NOR gate
IC2 MCP6002 MOS op amp
TR1 BC337
D1, 2 and 3 1N4148

Capacitors
C1 22µF electrolytic
C2 4.7µF 6.3V tantalum
C3 33nF polyester 5mm
C4 100pF 5mm ceramic
C5 470nF monolithic X7R ceramic

Resistors
R1 220kΩ
R2, R7 330kΩ
R3 1.2kΩ
R6 4.7kΩ
R8 33kΩ
R9 18kΩ
R10 1kΩ
R11, R12 100Ω

Pots
R4 1MΩ log 16mm
R5 100kΩ log 16mm

Miscellaneous
14-pin DIL socket
8-pin DIL socket
3 Molex style 3-pin headers

We'll give synths a break next month and find something new to play with, but I am going to upload a couple of videos to YouTube demonstrating the weird, strange and beautiful sounds that this design can generate.

In the future, there will be more analogue synthesiser modules from me, and Paul Cooper of Soundtronics will be taking analogue synthesisers to a whole new level with a large project in the new year.

Keyboard and circuit PCBs

I want you to build and enjoy these circuits. The PCB files, designed with free-to-use Eagle CAD are available without charge from the *EPE* website.

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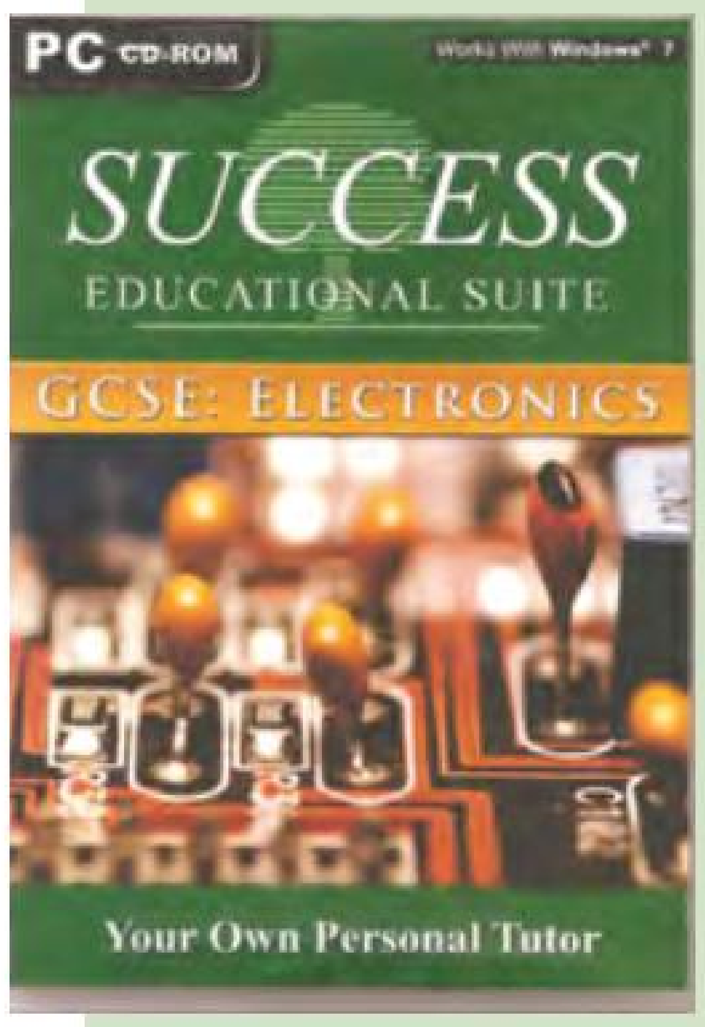

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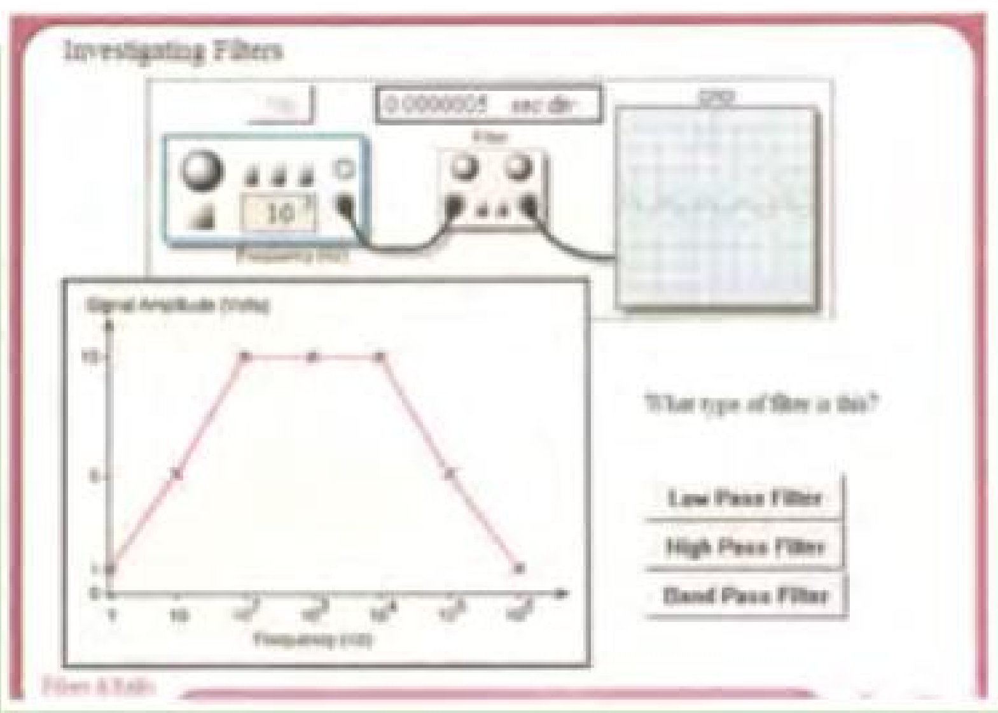

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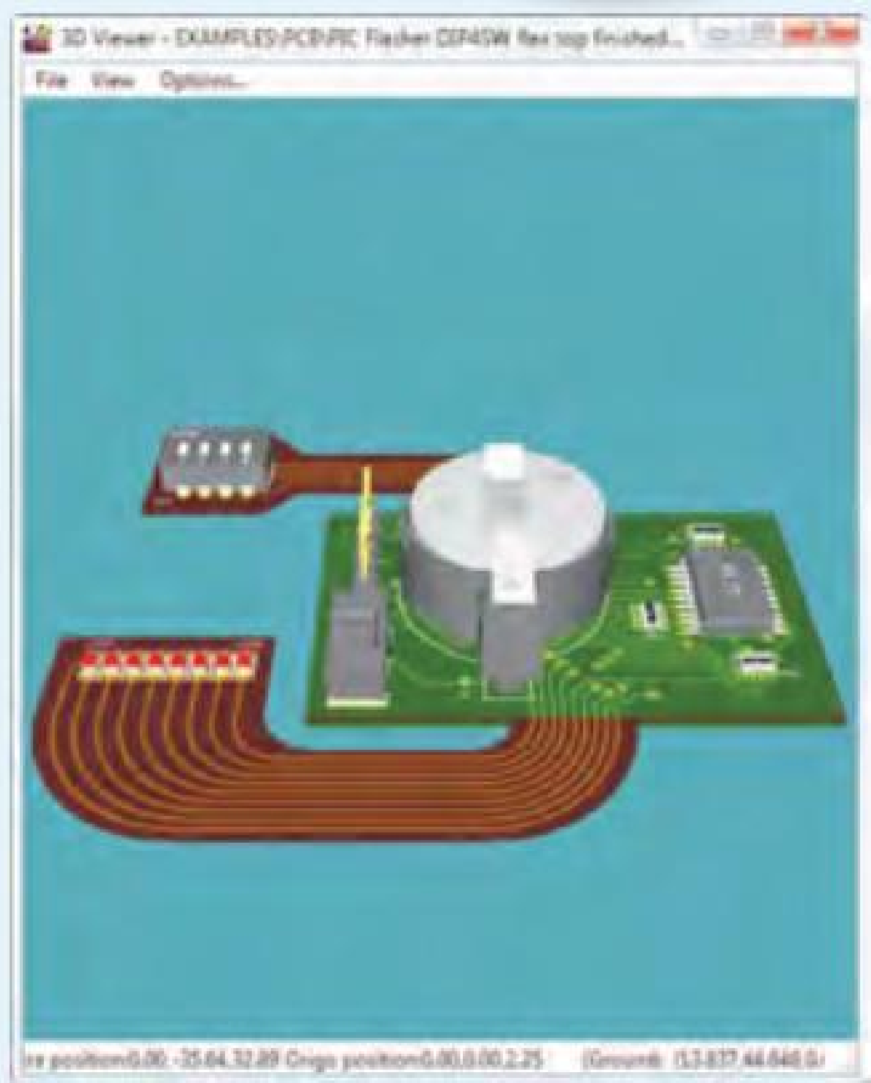

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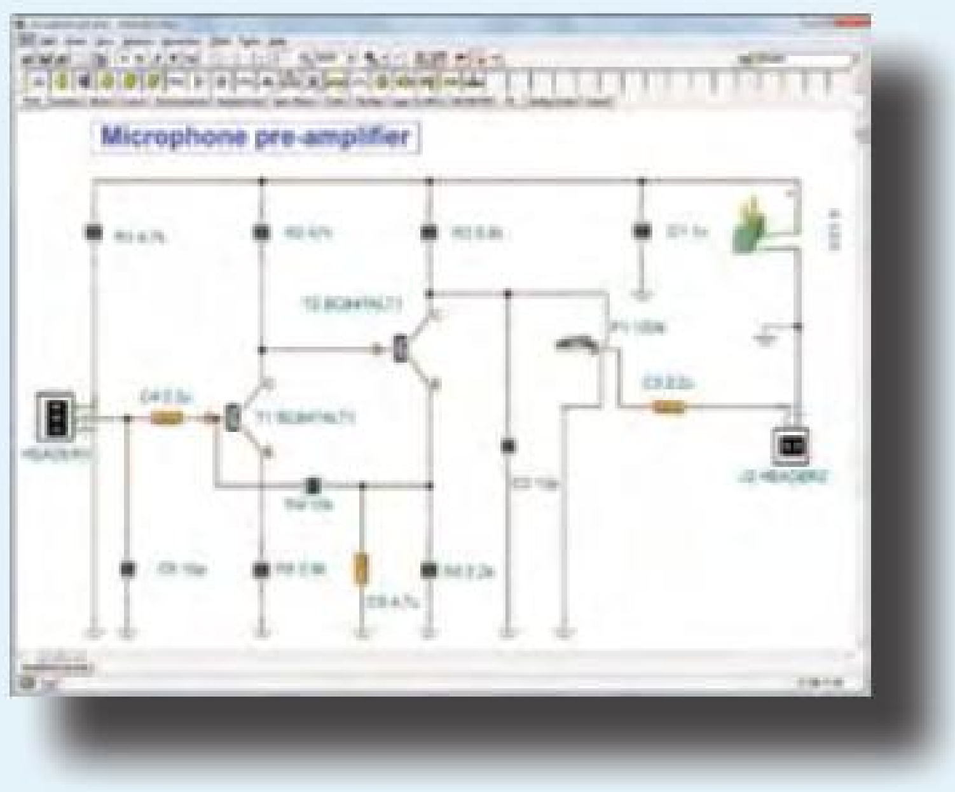

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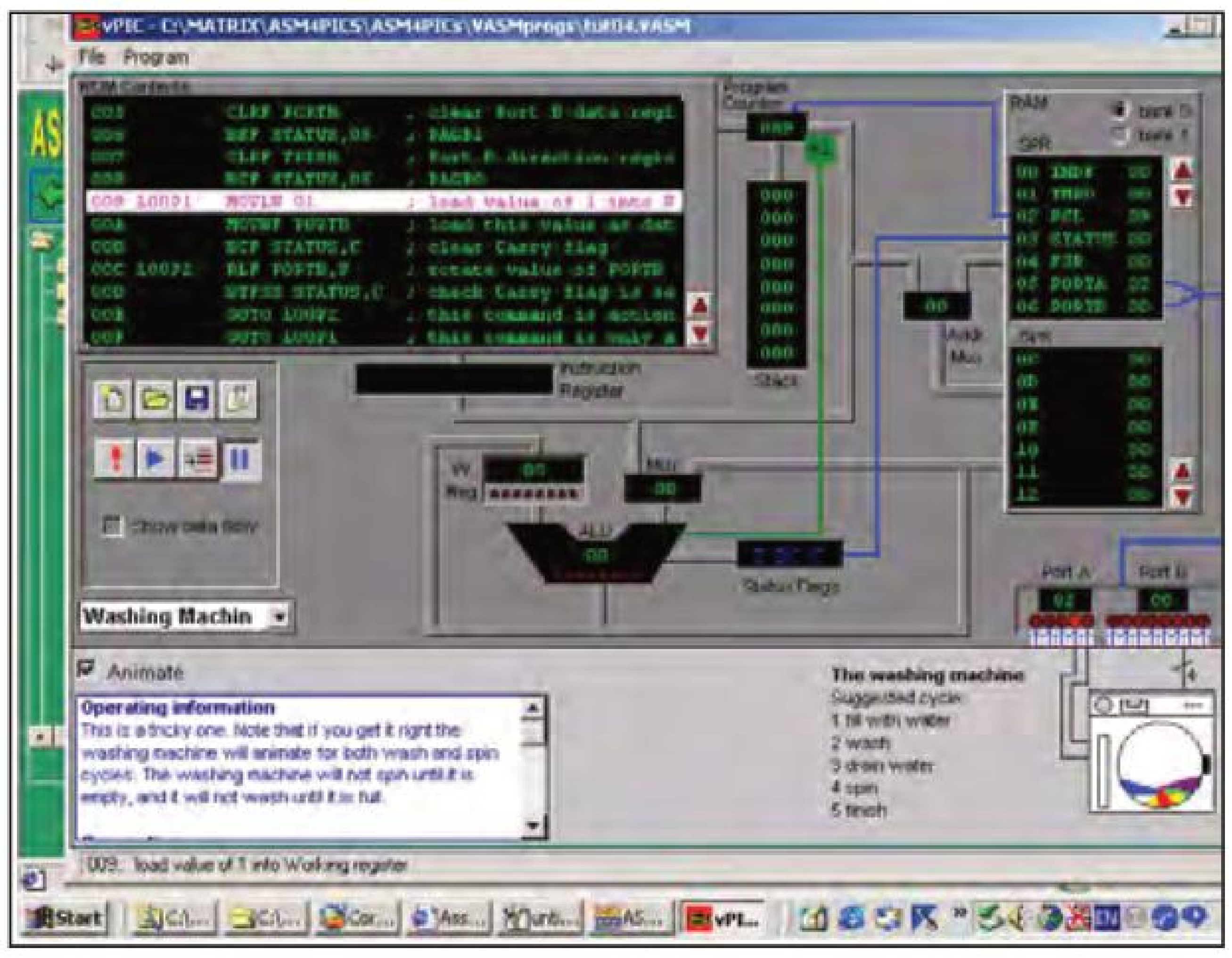

Operating information
This is a tricky one. Note that if you get it right the washing machine will animate for both wash and spin cycles. The washing machine will not spin until it is empty, and it will not wash until it is full.

The washing machine
Suggested cycle:
1 fill with water
2 wash
3 drain water
4 spin
5 finish

009: load value of 1 into Working register

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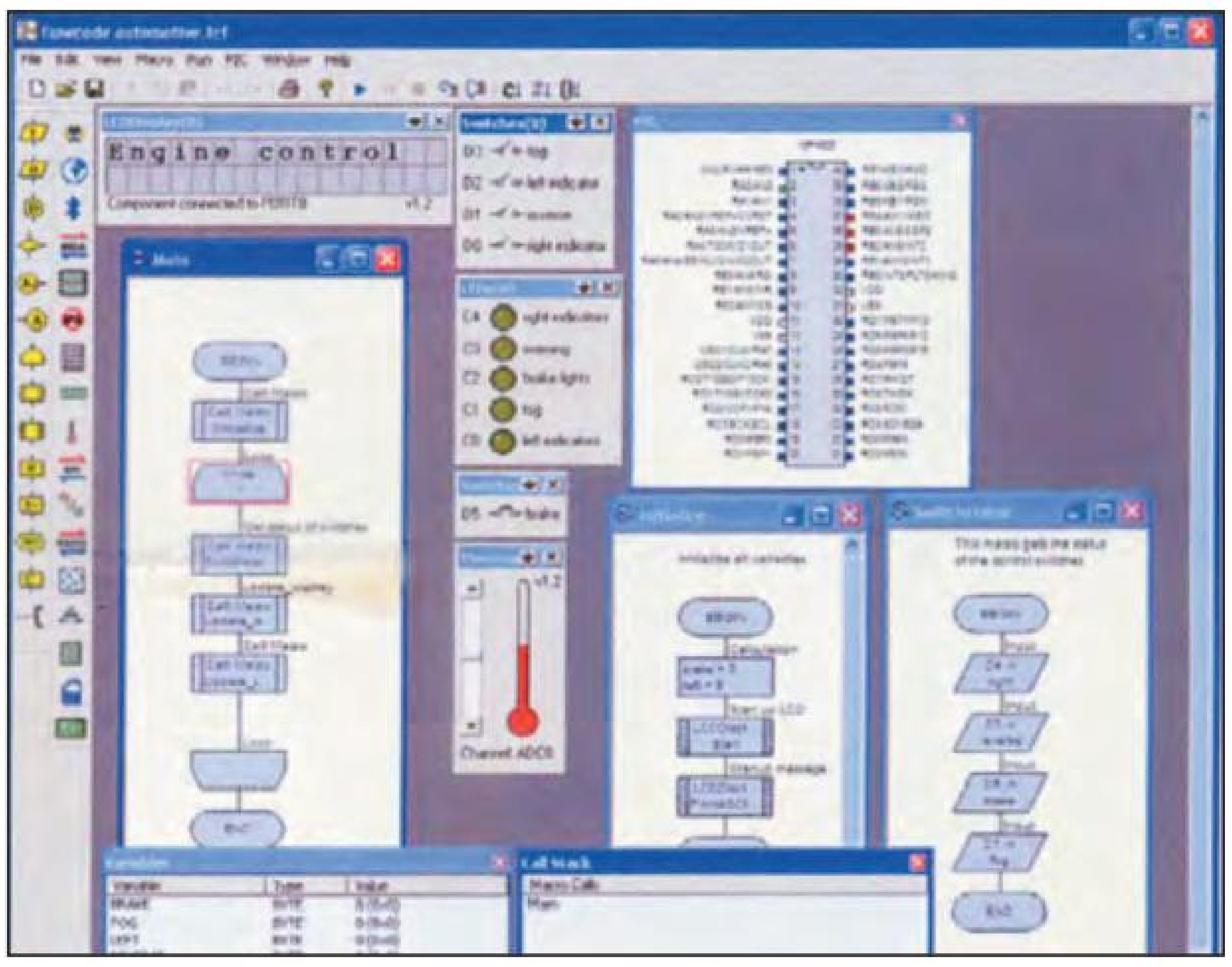

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The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

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The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

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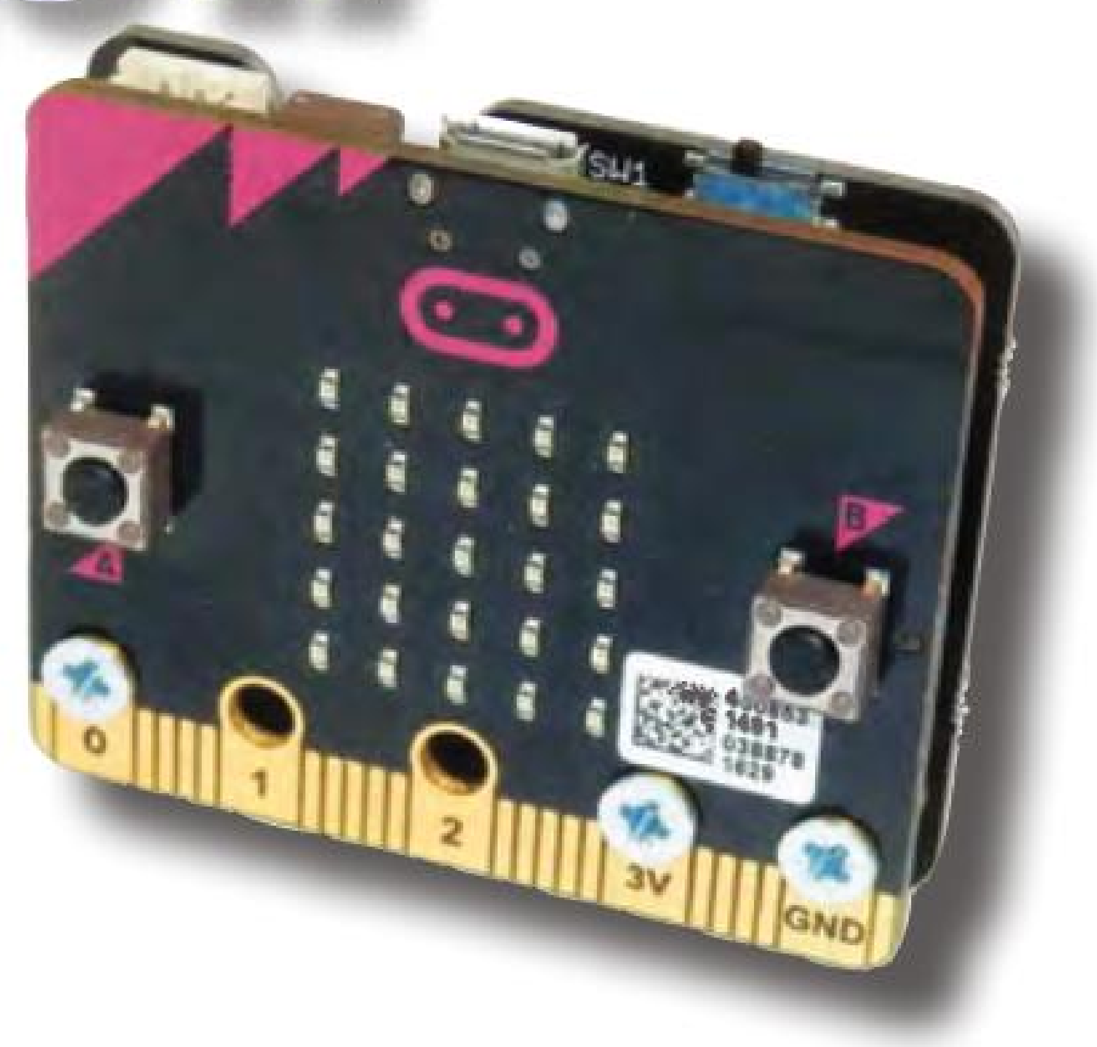
Teach-In 2017

Introducing the BBC micro:bit



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Python Coding on the BBC micro:bit
Jim Gatenby

PYTHON CODING ON THE BBC MICRO:BIT

Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: The main features of the BBC micro:bit including a simulation in a Web browser screen; The various levels of programming languages; The Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; Scrolling messages, creating and animating images on the micro:bit's LEDs; Playing and creating music, sounds and synthesized speech; Using the on-board accelerometer to detect movement of the micro:bit on three axes; A glossary of computing terms.

This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** £7.99

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For Beginners of Any Age
Getting Started with the BBC micro:bit
Mike Tooley

GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** £7.99

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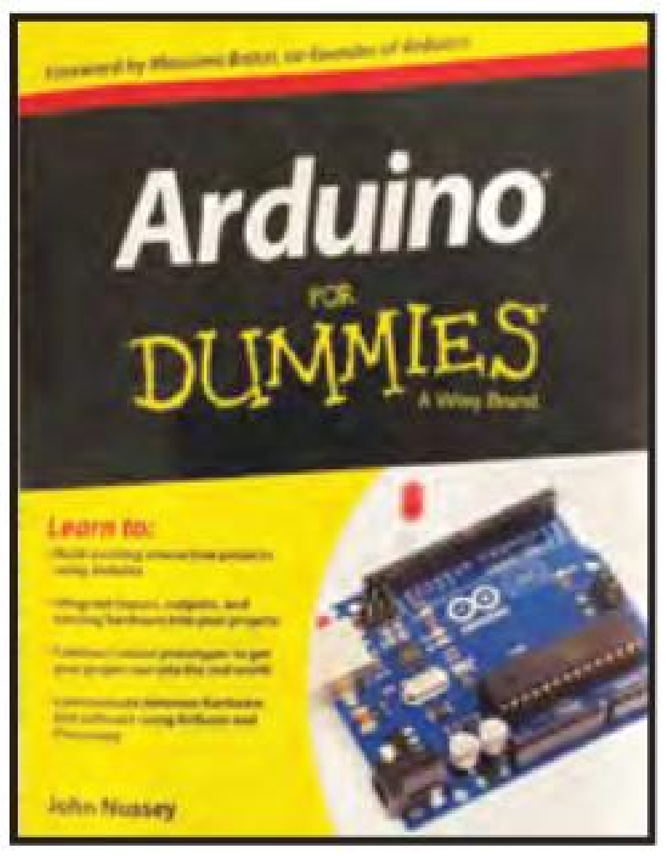
Teach-In 2016
Exploring the Arduino



ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

- Learn by doing – start building circuits and programming your Arduino with a few easy examples – right away!
- Easy does it – work through Arduino sketches line by line, and learn how they work and how to write your own.
- Solder on! – don't know a soldering iron from a curling iron? No problem! You'll learn the basics and be prototyping in no time.
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- Get social – teach your Arduino to communicate with software running on a computer to link the physical world with the virtual world

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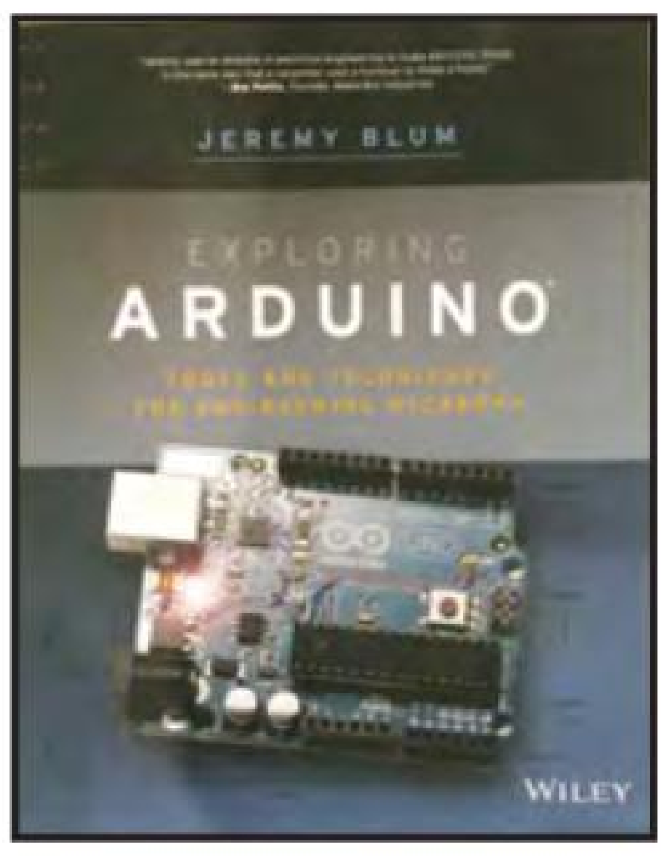

EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

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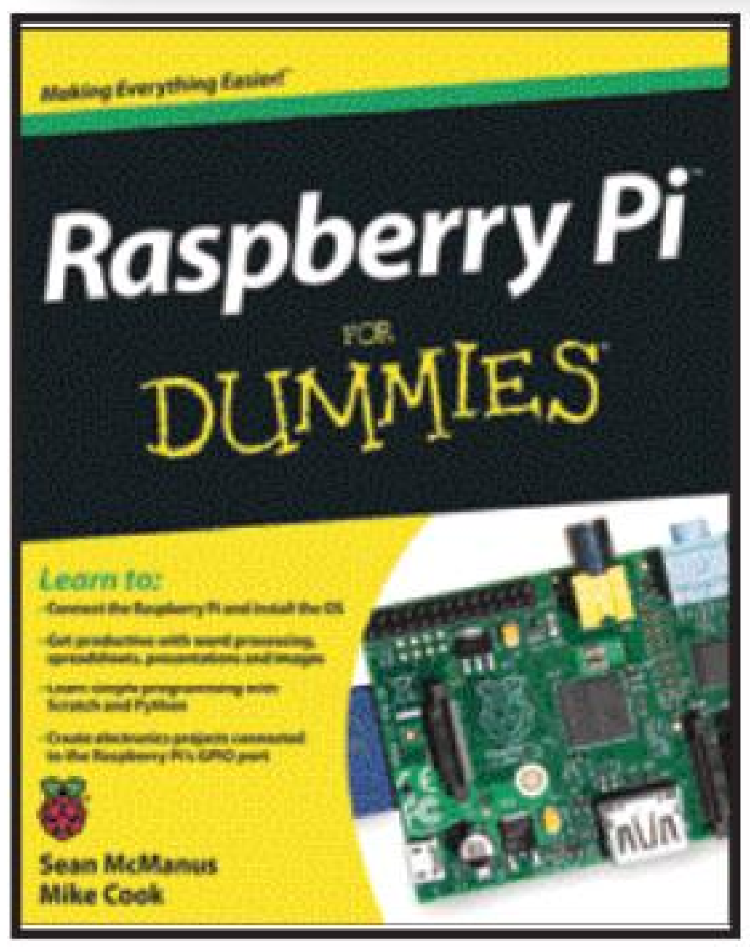

RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more! Open this book and find: What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

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ONLY AVAILABLE ON CDROM

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Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, Home Baking etc.

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Discrete Linear Circuit Design* Understand linear circuit design* Learn with 'TINA' – modern CAD software* Design simple, but elegant circuits* Five projects to build: Pre-amp, Headphone Amp, Tone Control, VU-meter, High Performance Audio Power Amp. PLUS *Audio Out* – an analogue expert's take on specialist circuits; *Practically Speaking* – the techniques of project building

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ELECTRONICS TEACH-IN 8 (Includes free CDROM)

ELECTRONICS TEACH-IN 8 – INTRODUCING THE ARDUINO
Mike & Richard Tooley

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This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project.

This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The Free CDROM includes files for Teach-In 8 plus Microchip MPLAB, IDE, XC8 8-bit Compiler and PICkit 3 User Guide. Also included is Lab-Nation Smartscope software.

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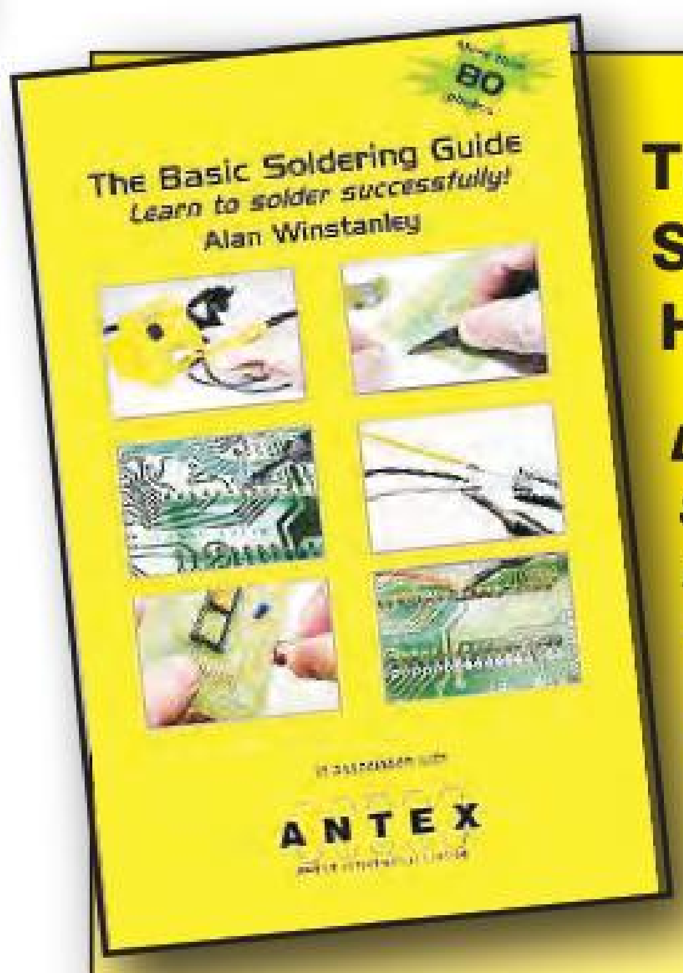

THE BASIC SOLDERING GUIDE HANDBOOK

LEARN TO SOLDER SUCCESSFULLY!
ALAN WINSTANLEY

The No.1 resource to learn all the basic aspects of electronics soldering by hand.

With more than 80 high quality colour photographs, this book explains the correct choice of soldering irons, solder, fluxes and tools. The techniques of how to solder and desolder electronic components are then explained in a clear, friendly and non-technical fashion so you'll be soldering successfully in next to no time! The book also includes sections on Reflow Soldering and Desoldering Techniques, Potential Hazards and Useful Resources. Plus a Troubleshooting Guide.

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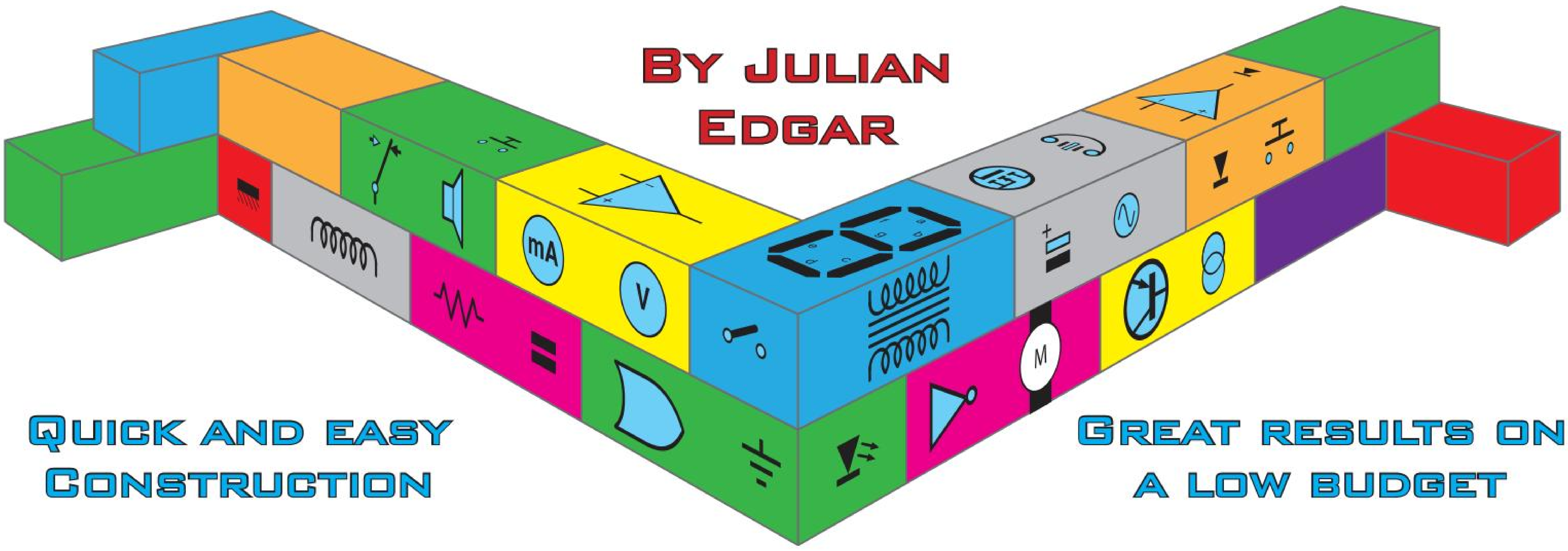
ELECTRONIC BUILDING BLOCKS



BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

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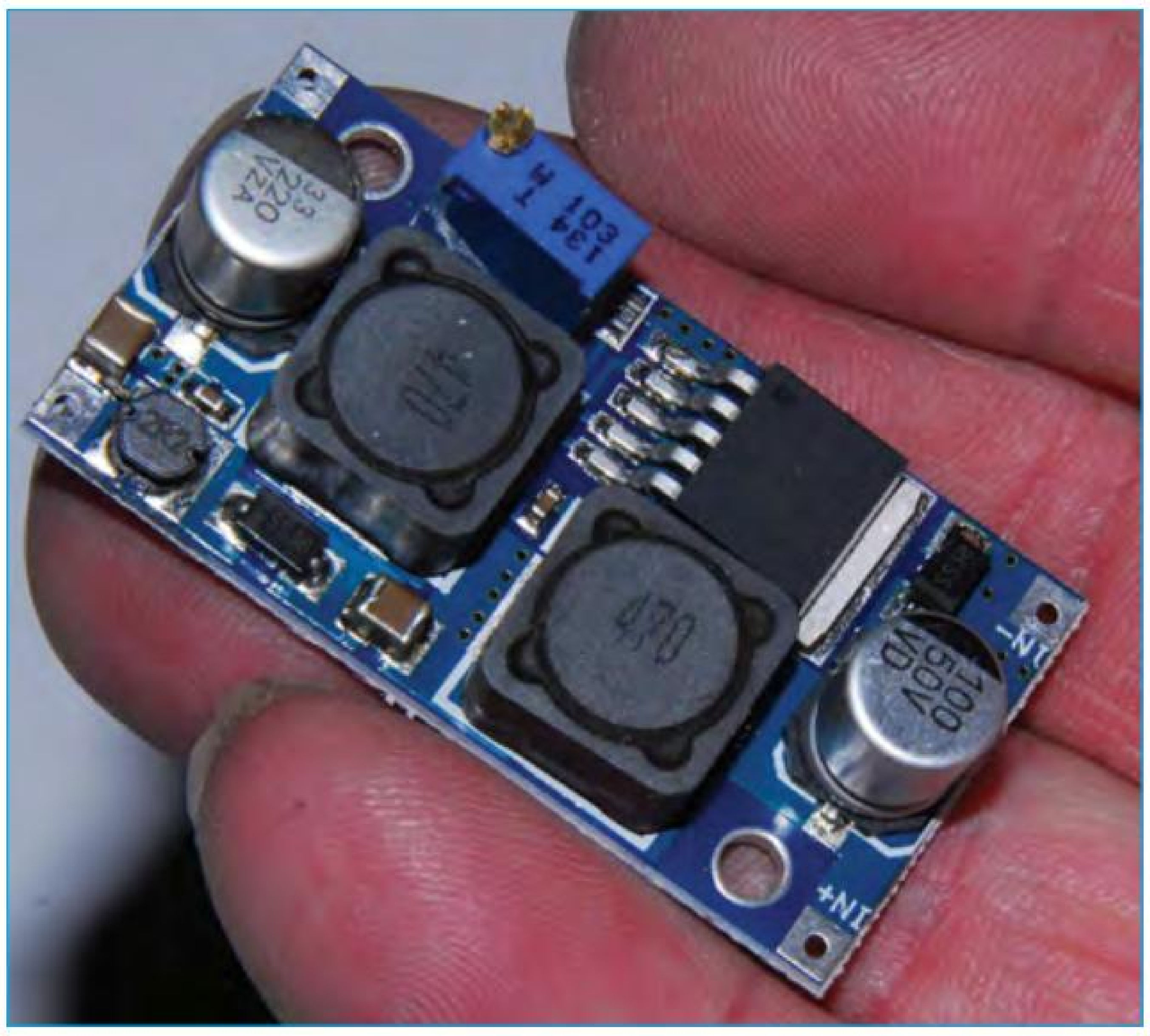
BUCK-BOOST MODULE

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

In most power supply applications, you need either a buck device (one that will provider a lower voltage than the supply) or a boost module (one that increases the available voltage over the supply). For example, if you want to provide 5V from 12V car power, use a buck module. Or if you want to provide that same 5V from two 1.5V cells, use a boost module. So when would you want to use a module like the one that's the subject of this column – a buck/boost module?



This tiny buck-boost module can output from 1.25 – 35V with a supply voltage anywhere from about 3 – 32V. A realistic input current maximum is 1A.

I can immediately think of one excellent application, but before we get to that, what can this module actually do? It can work on any input voltage from about 3 – 32V and can output any voltage from 1.25 – 35V. Maximum output current is claimed to be 3A and conversion efficiency is said to be 'up to' 94% (more on these latter figures in a moment). A multi-turn trim pot sets the output voltage, and it is maintained irrespective of whether the selected voltage is above or below the supplied voltage. That is, the module automatically bucks or boosts as required. The board is quite compact, at 48 × 25 × 14mm. It has two mounting holes.

Applications

So when would you need such a module? One use I can think of is when power is being produced by a human-powered generator (or rectified alternator). Let's say, for example, that rather than using rechargeable or non-rechargeable batteries to power your bicycle lights, you want to use a generator. (Hub generators work brilliantly on a bike, and it's a very satisfying feeling knowing that you're generating the power.) But the trouble with any generator is that its output voltage varies a lot with speed.

That makes using a generator problematic with almost any lighting device – even old-fashioned bike filament lamps used to blow if you rode down a hill too fast. (Or the generator was designed to lose efficiency at higher speeds – not a very technically elegant way of doing things!) Yes, you can run generator-powered LED head- and tail-lights with a dedicated LED driver circuit, but will that LED driver module be happy with such a wide range of input voltages – including a very low voltage when you're riding only slowly? (Fancy reading more about a bike light project? – just turn to page 38 for a really nice example.)

Just one of dozens of uses of the buck-boost module – running a 24V fan from a 5V supply. Great cooling, even off USB power!

Or take hand-cranked torches or power supplies for emergency phone recharging. It's easy to make a powerful and compact hand-cranked generator (use the motor and gearbox from a discarded battery-powered drill – just lock a crank handle in the chuck) but in any real-world application, you need to be careful who you give the generator to. (My 13-year-old son loves to show how fast he can turn the handle – 20V, here we come!) But by using this module, these issues are overcome.

And of course, having a universal module on the shelf means if you need to change supply voltage (either up or down), you can just grab this module.

The module is also ideal for human-powered devices, such as this hand-cranked torch. The voltage will be increased when the crank is wound only slowly, while also preventing problems when the handle is wound really fast.

Performance

So how well does it work? Overall, very well! Output voltage regulation was excellent, varying only a very small amount with input voltages over the full range. Output regulation with varying loads was also excellent. (The claim for load regulation is ±0.5%, and in use this figure seemed reasonable.) However, not so great is the current rating. At the nominated maximum 3A input, the module got *very hot, very quickly*. I then dropped the current to 2A and measured over 75°C on the output MOSFET. I then decreased current still further, settling on 1A – and still measured component temperatures of 65°C in a 20°C ambient. You could mechanically clamp a small heatsink to the MOSFET, but the design of the board means that would be awkward – better to just limit the module to 1A input current, max. With 17V input and 24.3V output, I measured an efficiency of 86% – there are losses; you're not getting something for nothing.

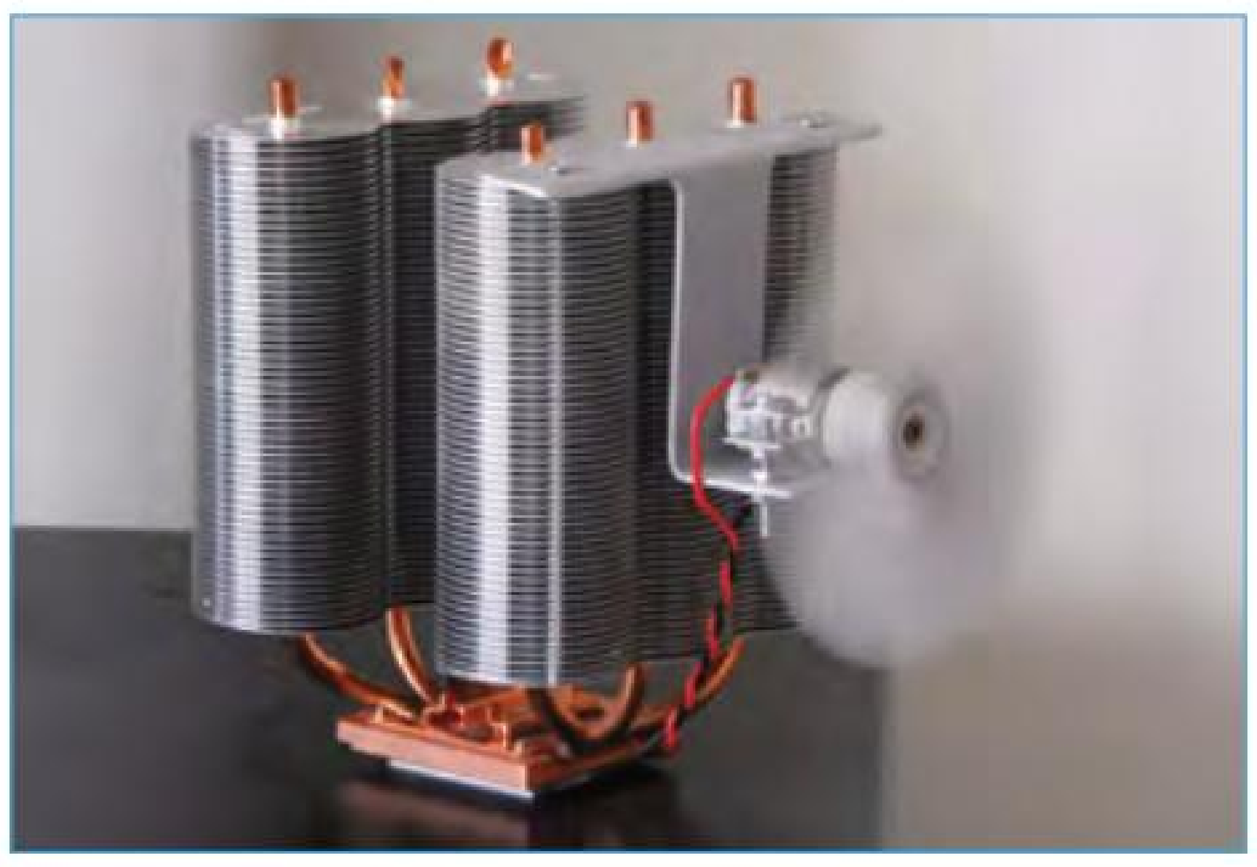
However, the more I played with the board, the more I liked it. As a test load, I used a 22V filament bulb – somehow, I've ended up with a few dozen of these old bulbs. Normally, you'd want to select the lamp voltage carefully when using it as a load, but with this module I just set the output voltage at exactly 22V – no issues. Then I grabbed a 24V fan – again, I seemed to have ended up with a lot of these. They're good quality designs, but as I seldom run 24V supplies, I rarely use them. But in this case, I just set the output to 24V. Any input voltage to the module, from 5 – 30V, ran the fan fine. (So now I can install these fans when using 5V USB power for a project.) Still with the fan connected, I then wound the output voltage down until the fan was just (silently) ticking over – so these modules can also be used to set the fan speed just as you require it.

Then I got some rather flat AA cells (around 1.2V each), placed four in series in a battery holder and powered a nominally 12V, 1W LED. Battery voltage sagged to 3.5V, but I ran the LED for many minutes – all from 'flat' batteries!

In all of these examples, there are other ways of achieving the same outcome, but I'd suggest none as easy and quick as using this module. For just over £2 delivered, it's convenience personified. Mine came from **www.banggood.com** – Product ID 1087346.

Next time

In my next column I'll be looking at a fascinating physical phenomenon and using it in a handy little application – a Peltier-powered fan for your wood-burning heater.



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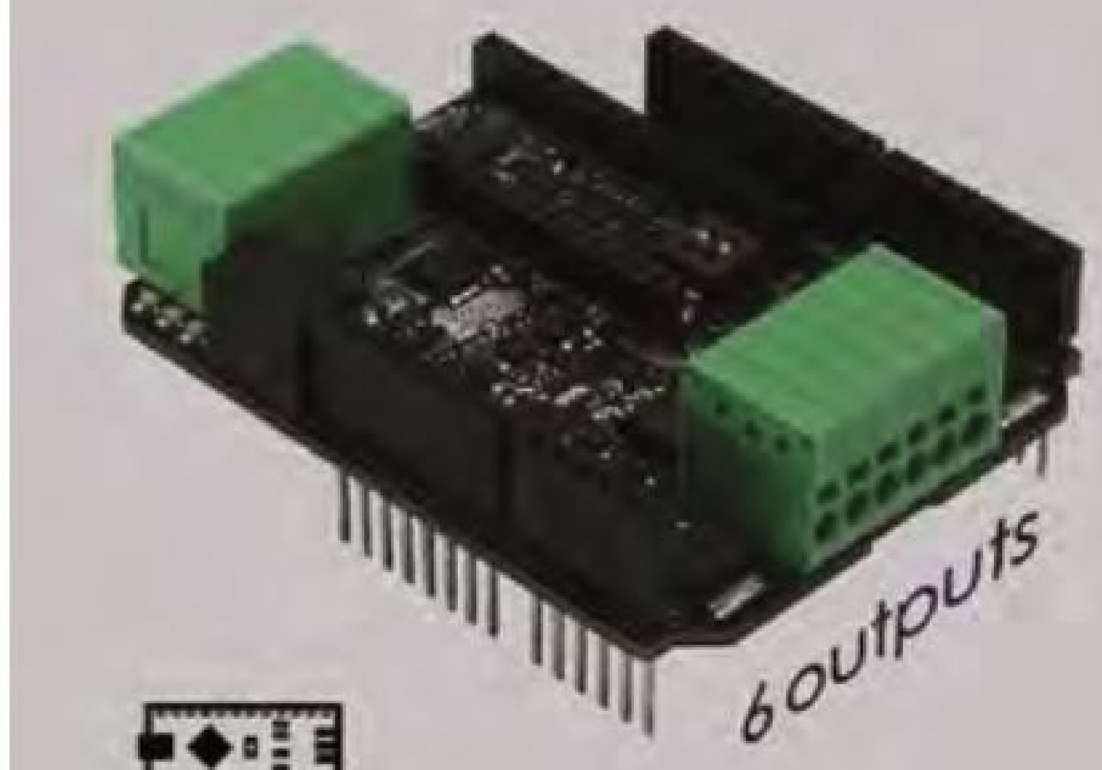

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NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

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DEC '17		
Precision Voltage and Current Reference – Part 2	04110161	£15.35
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Ultra-low-voltage Mini LED Flasher	16110161	£5.60
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6GHz+ Touchscreen Frequency Counter	04110171	£12.88
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NOV '18		
Super-7 AM Radio Receiver	06111171	£27.50

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Next Month

Content may be subject to change

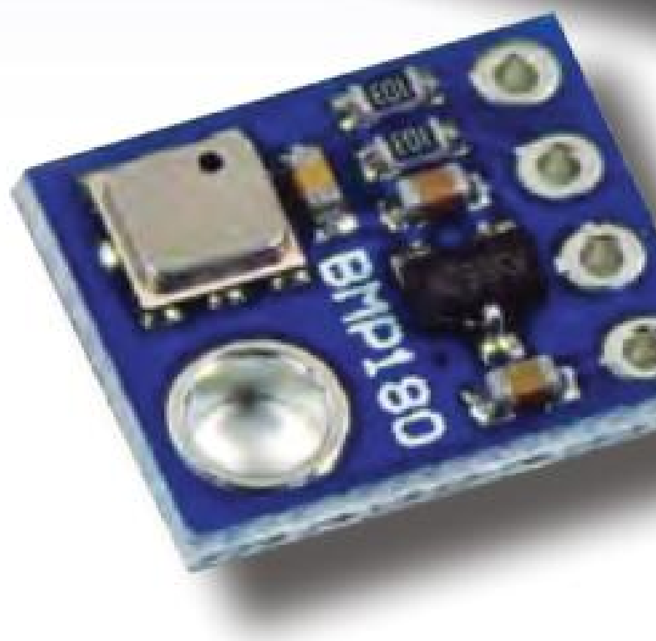
Touchscreen Altimeter / Weather Station
SOLAR PANEL CHARGE IN
USB CHARGE IN
ALTITUDE:
11
metres above GND
TOUCH TO CHANGE
MODE OR UNITS
SILICON CHIP
siliconchip.com.au
POWER

Touchscreen Altimeter

This accurate altimeter has a bright colour touchscreen to display altitude in feet or metres, atmospheric pressure, temperature and relative humidity. It can show all readings at once or provide a larger display for altitude – the most important one if you're flying!

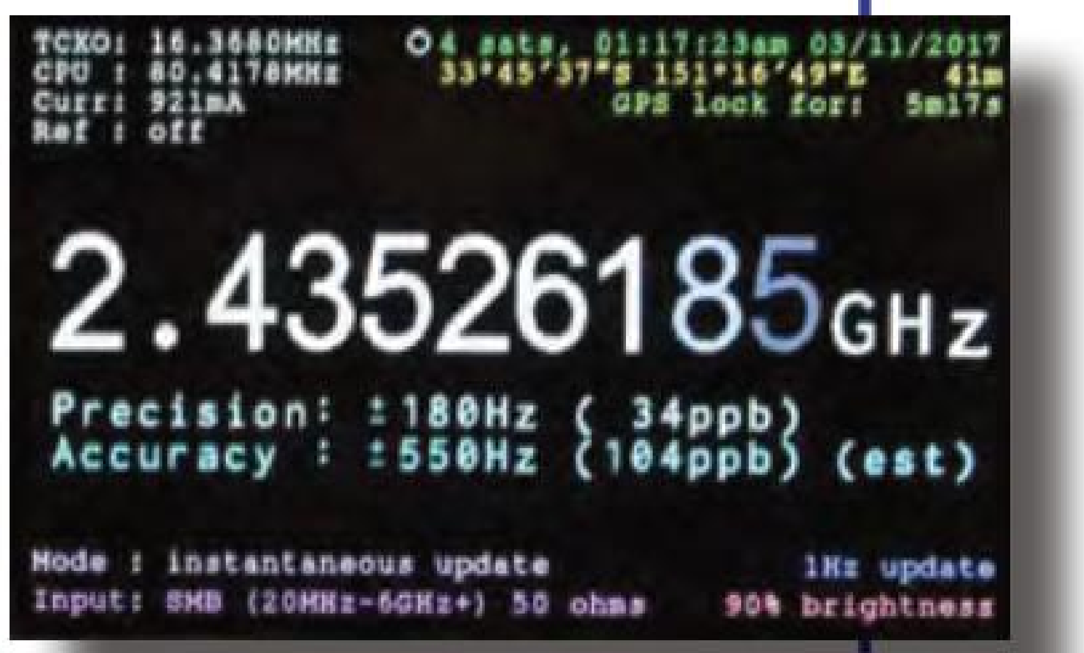
Super-7 AM Radio Receiver – Part 2

In this second and final article on the new *Super-7 AM Radio*, we show you how to assemble it, then align it for best performance and then put it into its superb case.



Low-cost Electronic Modules – Part 11

In December's EPE we're looking at two very tiny modules which sense barometric pressure and air temperature. Both can send their readings to virtually any micro via a standard I²C serial interface, plus one also offers an SPI interface.



```
TCXO: 16.3680MHz   ○4 sats, 01:17:23am 03/11/2017
CPU : 80.4170MHz    33°45'37"S 151°16'49"E    41m
Curr: 921mA                GPS lock for:  5m17s
Ref : off

2.43526185GHz

Precision: ±180Hz ( 34ppb)
Accuracy : ±550Hz (104ppb) (est)

Mode : instantaneous update              1Hz update
Input: SMB (20MHz-6GHz+) 50 ohms    90% brightness
```

6GHz+ Touchscreen Frequency & Period Counter – Part 3

Having described our new *6GHz+ Touchscreen Frequency & Period Counter* in the first article (October) and then built and tested it (November), we'll now show how to use it and explain what it can do. Apart from its very wide frequency range, it offers outstanding accuracy.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*.

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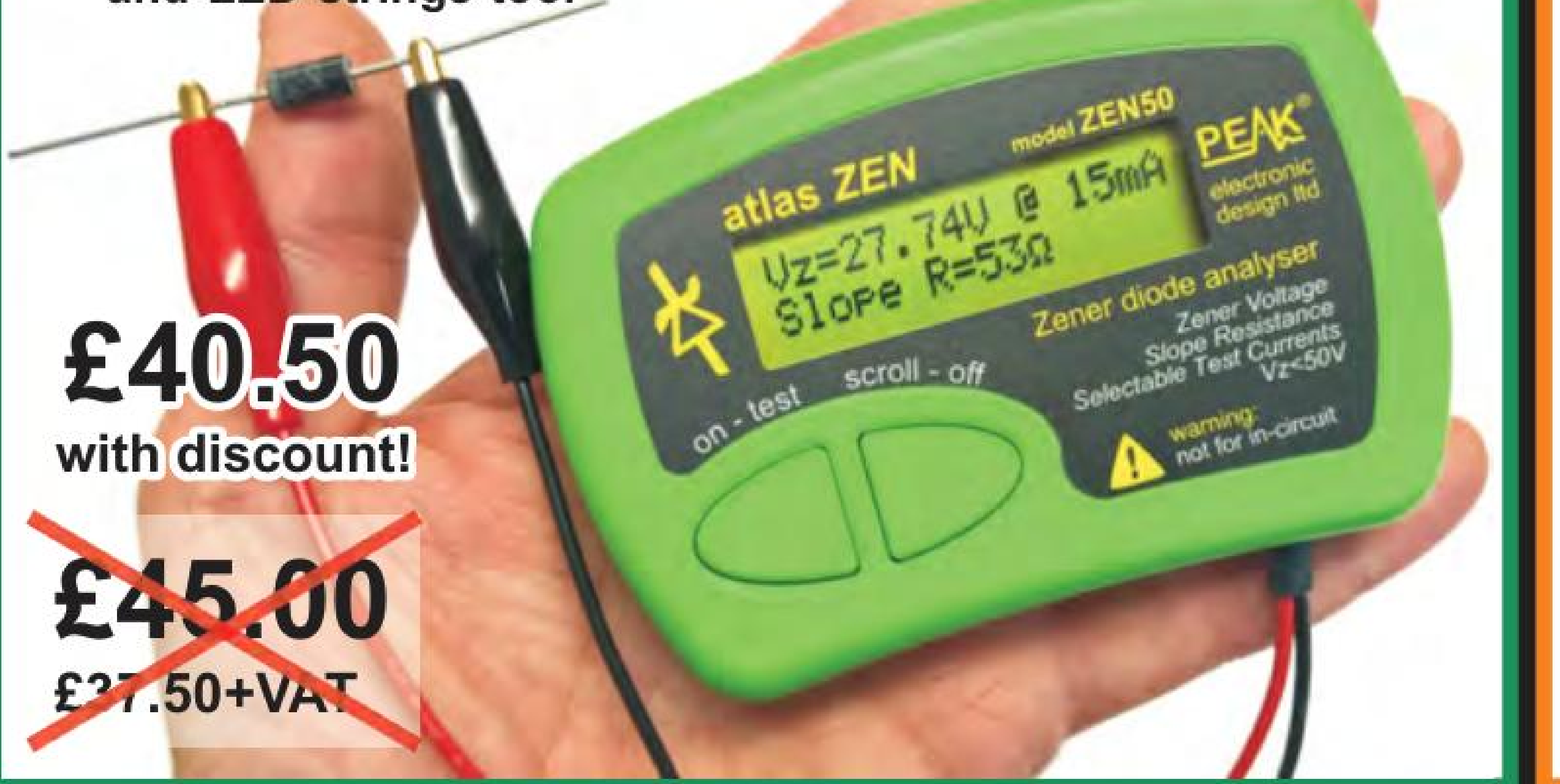
atlas ZEN
model ZEN50
PEAK electronic design ltd
Vz=27.74V @ 15mA
Slope R=53Ω
Zener diode analyser
Zener Voltage
Slope Resistance
Selectable Test Currents
Vz<50V
on - test
scroll - off
warning: not for in-circuit

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LCR and impedance meter
PEAK electronic design
Inductor 0.31Ω
L=701.1uH 15kHz
LCR45
on - menu
enter - off
warning: avoid charge/voltages

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~~£75.00+VAT~~

Component Summary
Inductor 23.6Ω
L=123.4µH 200kHz
Complex Impedance
Impedance 200kHz
+25.6 +j155.1Ω
Magnitude and Phase
Mag/Phase 200kHz
157.2Ω +80.6°

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VBE=1.039V
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scroll - off
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DCA75
USB + Graphics
PEAK
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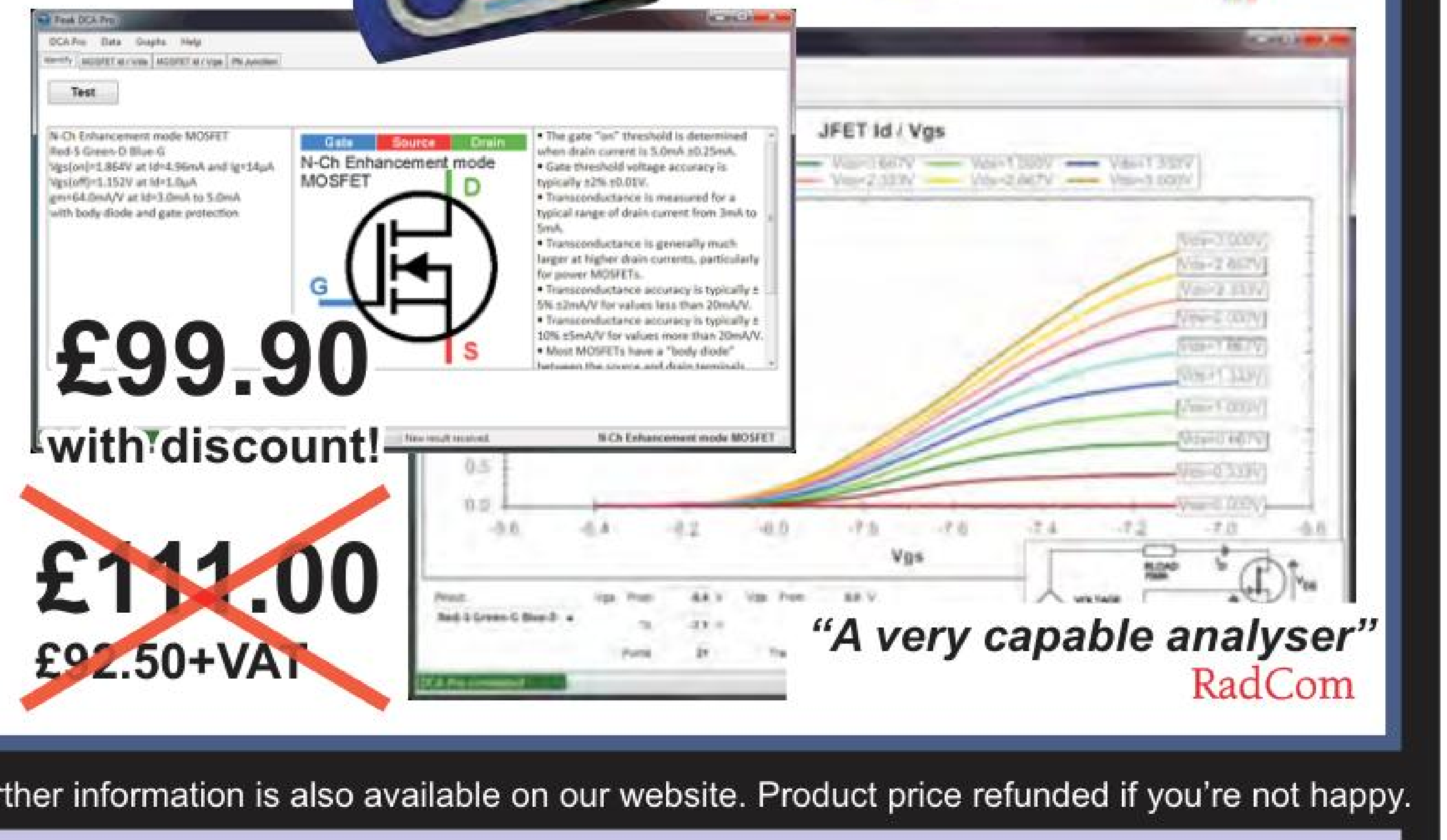
scroll - off
warning: avoid charge/voltages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Drain
D
G
S
JFET Id / Vgs
Vgs

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